Germany (Territory under Allied Occupation, 1945-
U.S.Zone) ~~Office of Military Government.~~
Office of the Naval Advisor.

PROJECT II FOLIA I

MARKNAGELUNG
NACH KUENTSCHER
(MARROW NAILING-MEDULLARY NAILING)

Part I
Symposium

Translation prepared by:
U.S.Naval Technical Unit, Europe,
(Medical Section) Office of the
Naval Advisor. Office of the Military
Government (U.S.).

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FOREWORD
TO THE TRANSLATIONS CONCERNING THE MARKNAGEL.

Perhaps the outstanding contribution of German surgeons during the past decade will prove to be the Marknagel (marrow nail) of KUENTSCHER. Following animal experiments concerning the nature of callus formation and the influence of mechanical factors on the healing of fractures he extended the principle of the SMITH-PETERSEN nail to the fixation of fractures of the long bones.

As might have been expected, his report on this method at the Surgical Congress in Berlin in 1940 was greeted with some amusement, some skepticism and even some derision. The introduction of such a massive foreign body into the hallowed area of the bone marrow was flaunting one of the most generally accepted theses of surgery.

However, the facts that healing did take place, that patients were weight bearing and being treated as outpatients unusually early, that certain well known difficulties in treating fractures were simplified, were all matters that could not be overlooked. The technique has a remarkable appeal to the mechanically minded surgeon. As often happens, the method was employed by some without a thorough understanding of the principles, indications and limitations. The predictable disappointment followed.

The procedure then entered the phase of the clinical test. Now it may be said to have gained a more proper place in the minds of orthopädic surgeons. Those who have a wide experience with the method use it successfully in cases where its use in less experienced hands would be folly.

The hazards of damage to the blood forming function of the bone marrow, of fat emboli, of delay of bone healing, of phlegmon of the marrow cavity, of infection of the fracture site have all been weighed. Most of these have been given their appropriate place as can be found in articles translated by this section. The question of whether or not to nail in the presence of an infected fracture site remains the item of greatest debate. Some well experienced in the use of the method advocate waiting for the acute phase of the infection to subside and then proceed to nail. Their reasoning is that the nailing does not cause such a spread of infection that this amounts to a contraindication but that the stability provided by a proper nailing actually aids in clearing up the infection and furthers the healing process. It goes without comment that other equally experienced surgeons consider this as hazardous.

Through all the discussions of this method the phrase "stabile osteosynthesis" recurs over and over again. This is, in the final analysis, the keystone of the entire matter. An ideal marrow nailing will achieve a "stabile osteosynthesis". The nail provides an internal splint, which at its best will prohibit the action of forces causing lateral displacement, angulation and rotation, - all forces which inhibit callus formation and bony healing -

while early weight bearing permits the action of the forces which press the bone ends together which favors callus formation and bony healing.

The fractures in which this ideal can be achieved are for the greatest part located in the middle third of the shaft of the femur. No other method of treatment offers the same advantages as are found with marrow nailing for this group of fractures. When this particular group of ideal cases is eliminated the use of the marrow nail becomes simply another possibility among a number of methods for fixing fractures. Its disadvantages and advantages will have to be weighed, along with the same considerations for all other known methods and the method most applicable to the given case may then be selected.

After having discussed this method with various surgeons, observed patients in the hospitals, reviewed case histories and X-rays, witnessed operations for the insertion and extraction of the nails it is my firm conviction that the marrow nail is here to stay in one form or another, just as certainly as the crutch. The principles concerned with its use are well within the grasp of any fundamentally well trained surgeon. The technic of the operation, though having its own special sort of pitfalls, is not complicated. As so often is the case in medicine and surgery, it is not the comprehension nor the mechanical ability but rather the judgement of the surgeon that makes the difference between a successful result and a less satisfactory result.

After two days spent with him, observing cases, reviewing histories and watching operations at his clinic, KUENTSCHER himself summed it up as well as anyone when he told me "It is no cure all, but it is a good idea, a lifesaving one in some cases",

This collection of translations is intended to cover various aspects of the use of the marrow nail. It is not intended that this project should be a complete library on the subject. Representative articles have been chosen for translation, several from unpublished manuscripts. The fact that a number of them originate from the orthopedic clinic at the University of Kiel is only natural. The largest single group of cases and surgeons associated with this method come from there. Other extensive groups of material have been available to BOEHLER in Vienna and HAEBLER in Hannover. BOEHLER has already published two profusely illustrated editions including his experience with this method. One ventures the opinion that time and experience has tempered his early enthusiasm. HAEBLER who was a surgical consultant for the Luftwaffe at one time had material on 800 cases of nailing done under his general supervision. He now regards it as an excellent method for certain carefully selected cases, and otherwise just another method - sometimes more suitable, sometimes less suitable than other methods.

KUENTSCHER, who probably has a larger personal experience than any other surgeon, unless it might be BOEHLER uses the nail more freely in border-line cases than the others. He served on the Finnish Front during the war and since the cessation of hostilities has been practicing in what, by American standards, are positively primitive surroundings - his clinic was formerly a run down institution for feeble minded children. When this writer visited him in November of 1946 the beds of this strange place held the most astonishing assortment of the backwash of orthopedic surgery within recall.

It seemed as though the failures of other surgeons, the "too old" patients, the cases of faulty union, old cases of pseudarthroses, literally the lame and the halt of all kinds, had heard of this man and made their way to him. These people came to him as a "last hope" in many cases, willing to risk any hazard. The conditions under which he has had to practice these past several years and this attitude of fatalism of many among his patients probably has had an influence on his point of view.

Certainly KUENTSCHER uses the nail in a wide variety of cases not considered suitable by others. He says he is himself astonished many times - that he uses it often only because other methods have been tried and failed and the patients have come expecting to be nailed. One comes away from this hospital with the feeling that the patients get well here when they did not elsewhere because of the patience of this shy man - and a "stabile osteosynthesis".

One may wonder why a former professor of surgery at a university medical school is working in such an environment. He says it only goes to show what youthful idealism can do to a man. After several visits and a number of hours together I asked him how this happened to him. His story has been confirmed elsewhere. In the formative years of the National Socialist Party in Germany, while a student, he joined the group out of idealistic opposition to Communism. He is a quiet, shy person of the true scholar type - still a bachelor. People who knew him well state emphatically that he was an idealist entirely out of step with Hitlerian policies. They say that it was his quiet nature that caused his downfall - that although out of sympathy he did not (or could not) resign from the party. He was not too well in favor with the "powers" in the Army as suggested by his assignment to the Finnish Front where he was "forgotten". His being isolated on the Finnish Front for so long is considered by several of his acquaintances to be proof positive that he was considered "politically unreliable" by the Nazi party. A curious aspect of this is the hearty foreword given the booklet "Die Technik der Marknagelung" by A.W. FISCHER, a well known Nazi in Kiel. Although KUENTSCHER is listed as an author he disclaims any authorship.

Now that the war has ended his record indicates long time party membership and consequently he cannot hold any university position. Under these circumstances he may be well off where he is, because he is at least allowed to practice his profession. There is hope that with the passage of time, and the quieting of propaganda, sober individual consideration may be given cases such as his and that he may be re-established in better surroundings.

Several books on the marrow nail have been published. It appears that the first such book was prepared as early as 1942, "coauthored" by KUENTSCHER and MAATZ - contemporaries at the University of Kiel. Due to circumstances of the war it did not actually leave the presses until late in 1944. KUENTSCHER quietly disclaims all association with this booklet which is principally a discussion of technique. In 1944 HAEBLER of Hannover brought out a pocket sized war edition "Die Stabile Osteosynthese (Marknagelung nach KUENTSCHER)" published in Munich.

BOEHLER has published a profusely illustrated editinn of his work on fractures with an extensive consideration of the Marknagel which appeared in 1945. In 1946 a volume in French was brought out by R. SOEUR of Brussels. It was printed in Belgium.

Both HAEBLER and KUENTSCHER now have in preparation their personal experience with this method. Both of these works will be worthy of careful reading.

These translations are offered without any apologies. The translation project of this section was conceived as a worthy contribution of the Medical Corps of the Navy to the scientific literature of English reading peoples - making available selected information before it might be generally available considering the shortage of printing facilities, limited availability of German journals and the backlog of unpublished manuscripts and uncompiled research data and the general neglect of clinical medicine and surgery by technical intelligence organizations. The excellent FIAT Reviews have done much to correct this threatened oversight in a general way. One will still have to go to the original literature for details. Lt. Col. James BLAISDELL of the Medical Corps of the Canadian Army, who did yeoman service as the editor of the FIAT Reviews in Medicine, regretted this fact deeply and did all any one man could to overcome it.

During the period of parturition, these translations have been beset by a number and variety of troubles impossible to imagine beforehand. Now that their accouchement is at hand the father of the project can only draw a weary breath and beg indulgence for any faults the reader may find in the offspring. It has been a long and tedious labor, but we like this child.

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Reprint from the
ZENTRALBLATT FUER CHIRURGIE
68. Jahrgang, Nr. 19 - 1941
Verlag von Johann Ambrosius Barth in Leipzig

From the Surgical Clinic, University of Kiel
Director: Prof. Dr. A. W. Fischer

CALLUS WITHOUT FRACTURE

by
Doz. Dr. med. habil. Gerhard Kuentscher
Oberarzt der Klinik

With 7 Illustrations*

*(Illustrations Nr. 2a and 5 could not be reproduced because the negatives were no longer available.)

Translation prepared by:
U. S. Naval Technical Unit, Europe, (Medical Section)
Office of Naval Advisor
Office of Military Government (U. S.)

When a fracture occurs the broken ends of the bone, and especially the area surrounding them suddenly engages in a rapid development of a special tissue, namely callus tissue. In the unusually extensive literature which has been compiled concerning callus, there is no unity concerning the important question as to how this development is initiated. It is only known with certainty that when we find this situation has developed abnormally, as in the case of a pseudoarthrosis, there is no other alternative than to create a fresh fracture (by the splitting method of KIRSCHNER, the sawing method of BRANDIS or the drilling method of BECK as example etc.). The growth of callus is explained as a re-sult of irritation which might arise from substances in the hematoma or in the damaged tissues, from the marrow or the hematoma itself or may be attributed to the acid reaction of the tissue which follows inflammations. It is not possible by simulation of this irritation (by creating an acidity in the tissues, injection of hormones, hormon-like substances or vitamins as from ones own blood) to produce a display of callus grwoth such as is seen in fractures or following the above mentioned methods of stimulating the growth status of the bones. Likewise, a second important question is not clarified, from which part the callus growth arises, if from the marrow, from the periosteum or from the surrounding connective tissue. This is the difference of opinion between BIER and LEXER. As BLOCK (1) in his excellent book "The normal and delayed healing of fractures", has pointed out, the proper significance was neither attributed to the marrow by BIER nor to the periosteum by LEXER. Each one of these men considered the factor they supported as being <u>exclusively</u> important. It is with this relationship of the irritation to callus formation as with so many other events in the living organism; a number of causes and potentialities exist and exert their influence simultaneously.

All other things being equal, the further development of callus depends on the kind of treatment. The mechanical factor plays the most important part at the fracture site. PAUWELS could show this by calculations in the case of a fracture at the neck of the femur. The author arrived at similar results by a direct description and measurement of the effective forces. The treatment of fractures by traction appears far less favorable in this connection than the treatment with Plaster of Paris. Least favorable appears the operative treatment of a new fracture, for in this case the damage to the periosteum by exposure, separation of tissues and bruises by wires, screws, etc., as well as the loss of the hematoma, are additional unfavorable factors. Of all procedures, however, the most favorable circumstances are obtained in the case of marrow nailing. The nail protects callus from all the harmful pulling and pushing forces and the shearing effect and so permits only the influence of the favorable forces. Thus we see, as experience has shown in more than 90 cases (1941) always an extraordinary strong development of callus, even though dealing with relatively small fracture clefts, a circumstance usually accompanied by very little callus formation. (It is in the very nature of marrow nailing that the repositions are exact to a millimeter). In addtion to this, the other parts of the mechanical unit, consisting of bones, muscles, and joints do not suffer any damage, for early motion after nailing is quite possible, as the nail in the marrow is itself capable of replacing the mechanical stability lost by the fracture. Therefore, the damage remains limited to the bone. Also the circulation of the damaged limbs and the rest of the entire human body is not effected

Illustration 1

Within a short time reports will be issued about the extraordinary successes of this procedure at another place. All these reasons are often not sufficient to account for the formation of such considerable quantities of callus as are commonly seen in this procedure. Further the observation of X-rays leads to the impression that there is also a strong irritation caused by the nail in the marrow. On occasion, in cases of fractures in the middl of the femur the callus formation can be seen to extend as high as the trochanter minor. Thus we have the frecuently occurring picture of the periosteal piling-up (Ill. 1).

Attempts of the author to bend sound bones by inserting springy marrow nails in the bones of dogs have proven that such a possibility exists as a result of irritation. Originally this work was undertaken to clarify the question of the possibility of straightening the crooked form of long bones, as they are found in the cases of the so-called "late rachitic" changes, by the use of appropriate nails. As is well known these changes cannot be corrected satisfactorily. It was hoped to obtain such alterations in the shape of the "crooked bones" in dogs. Strong spring blades were percutaneously inserted into the marrow cavity. This is a very simple operation. The thigh or leg is held in the left hand and at the appropriate place, which must be well shaved and antiseptic, a hole is drilled in the direction of the marrow cavity with a square awl held in the right hand. The direction is determined by palpation by virtue of the fact that the marrow cavity is almost exactly in the middle of the left fist. Then the awl will be drilled deeply into the marrow cavity. On the femur the end of the trochanter major is the place of puncture and in the leg the area just above the tuberosity of the tibia. This latter point is situated outside the capsule of the knee-joint. Neither the knee joint nor the hip joint will be opened during the operation. Now marrow nails in the shape of semicircular spring blades are introdueced. These springs are inserted in an extended condition. (Most often several springs were introduced over each other). The introduction was facilitated by the fact that the ends of the springs are rounded off and bent slightly in the direction opposite to the principal curve (Ill. 3) The skin is closed by a suture. Immediately after the operation the dogs were able to run again without any inconvenience. For skilled operators the operation requires only some minutes.

Illustration 2b

The length of the spring was, according to the dogs in use, 100 to 120 millimeters, their width 3 to 5 millimeters and their thickness 1 to 3 millimeters. By these differences in the strength of the springs, the constant bending pressure they exert can be unequally distributed throughout the full length of the long bones. Each single spring develops a bending power between 1 and 5 kilograms. Therefore, by the use of several springs, up to 25 kilograms bending power can be exerted in the marrow cavity of a medium sized dog. Thereby the marrow cavity was well filled up. By four preliminary trials, lasting more than fifteen months, it was demonstrated that a complete filling up of the marrow cavity with wires or rods of V2A-steel or of glass did not produce the slightest recognizable alterations in the X-ray, unless these wires or rods were so strongly driven into the marrow cavity that they created a constant pressure by an extension of the normal elasticity of the marrow space (Ill. 2).

Ill. 2a could not be reproduced because the negatives were no longer available.

Finally these results during the formation of callus could be caused by a special nail, the split end of which can be spread wide at its head by tightening a screw. This spreading is done by an enormous pressure, the degree of which, however, cannot be readily expressed in numbers.

Further, these experiments demonstrate that considerable destruction of marrow does not have any demonstrable influence on the bone itself. On the other hand, the tremendous formation of callus sometimes seen, cannot be considered as an indication of severe damage to the bone.

The result of these experiments with the springy marrow nails used in the bones of 6 dogs were in all cases comparable and extremely surprising. By the formation of surrounding callus the bone strengthened itself and remained absolutely straight in spite of the bending pressure, and the expected atrophy of the bones or bending of the shaft of the bone did not occur (Ill.3).

This reinforcement of the bone was so pronounced that the weight of the bone was doubled. As the mechanical stability of a tube under generally equal circumstances depends on its external diameter (distance from the circumference to the mechanical axis) this would mean a very considerable improvement of the mechanical stability. These effects are limited, however, as the newly formed bone is softer and the original compacta is partly absorbed. This new bone is so soft that it can be cut with a knife and therefore is especially suitable for bone grafting (Spannplastiken), particularly as we have to deal with this extraordinarily active growing tissue. I have therefore called it "Os activum". As animal experiments show, this os activum does not die off and it is not replaced by a new tissue at the place of transplantation but it continues its active growth.

Illustration 3

As can be seen in the accompanying photographs of X-rays this callus has grown radially. Because of this the surface of the thickened bone feels rough. In cases of a mild irritation one sees only a piling up of the periosteum with a clear intermediate space between the corticalis and the callus. In the cases of a moderate irritation of the bone, there is an equal thickening, which can be clearly recognized as arising from such accumulated callus. Some weeks later the X-rays show a gradual disappearance of the margin between corticalis and callus. Then the cortex begins to show a calcium deficiency which appears as large uneven irregular lines of absorption or as striations.

Later both the marrow cavity and the margin of the end of the cortex appear cloudy. This cloudiness is not only due to the periosteal callus lying externally but it is also a sign of a strong endosteal formation of callus. This is shown by the formation of a layer, 1 millimeter thick, around the nail or wire in such a way that the endosteal callus does not completely grow to the nail.

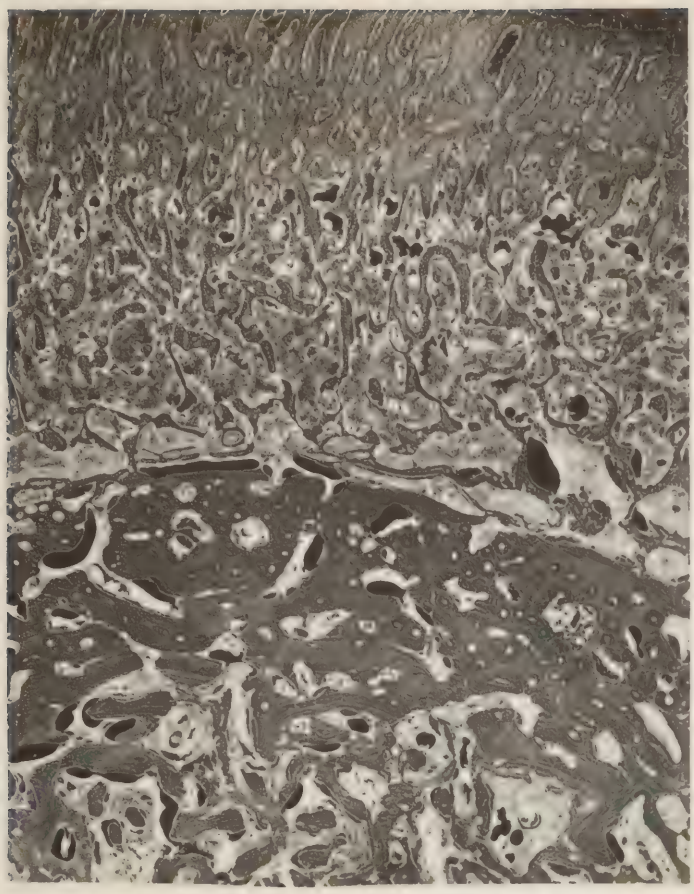

Illustration 4

The histological picture shows a marked formation of new bone (Ill. 4). The margin between the external layer of the old "os compacta can be clearly recognized. While the old compacta in this case (demonstrated in Ill. 4) is 2,1 millimeteters thick, the thickness of the newly formed bone amounts to 16 millimeter. This new bone shows all sings of a rapid and stormy growth. In contrast to the old bone, this new formed bone is of connective tissue nature. It shows an extremely orderly growth of the bone with a beam like structure, of the bone spicules which are placed exactly radially. The periosteum is thickened and at places extend inwards as pegs, according to the radial arrangements. The newly formed bone arises from the periosteum. This is clearly demonstrated by the fact that the newest bone is situated at the external circumference and that the bone is older closer to the middle. Thereby the margin between the old cortex and the new tissue can be clearly recognized. No proliferation of the old bone can be observed.

Within the newly formed callus there are two zones clearly recognizable. This fact is clearly demonstrated in the pictures. In both zones a very active growth occurs. In the external layer the marrow spaces are thightly packed together. They are associated with the vessels coming from the periosteum. The older inner zone shows wider marrow spaces. Here the bone begins to put itself in order according to the plan described by MAYER. In the outer zones "Osteonen" arise. Here the secondary reforming of the vessels takes place. The marrow spaces are filled with new marrow and those in the outer areas of the cavity are filled with high osteoblasts arranged like palisades. In the outer layer no signs of absorption can be noticed. No evidence of an osteoblastic bone resorption can be identified but everywhere only a very active new growth can be seen. Some of the wide marrow spaces show markedly dilated lacunar blood vessels filled with blood. The high osteoblast layers of the marrow cavity surround the newly formed bone substance which, however, does not yet, or at least not quite completely show the process of the growth of an "osteon". The structure therein is quite regular and there are no irregular lines of healing visible as in the cases of Paget's disease, etc. The entire marrow cavity discloses a distinct radial growth of this sort conditioned by the course of the vessels. In this respect this is different from the histological picture of the callus seen in cases of fract-

ure. Some of the outer lamellas are considerably thickened. Some of the inner layers open and extend into the marrow spaces. The old bone marrow does not show any particular alterations. Neither here nor in any other part of the bone can necrosis, processes of degeneration or any other signs of damage of the tissue be recognized. Only immediately next to the nail an infiltration of the tissue with iron occurs. A similar development starts from the inner periosteum thereby filling the marrow cavity with small bone spicules.

In one single case treated with a marrow nail slight clarification of the cortex, starting from the periosteal callus, could be recognized. For this observation I am obliged to EHRLICH (Hindenburg) who reported it as an additional finding along with an adequate callus formation during one of his femur nailings.

In their transient appearance and the impression they give, these findings are very much like the thickening of the ulna of the dog after the resection of the radius as we have seen in the experiments of Martin W. MUELLER, as well as others. There is no doubt, therefore, that in both cases we are dealing with the same process. The same cause applies in both cases. Also in this latter case the bone is suddenly subjected to far more strain than usual. Opposite to the place of resection the bone (ulna) thicknes tremendously. As the author could demonstrate, the ulna and radius of the dog form a mechanical unit being tied together by strong ligaments. The place of resection acts like a notch cut into this unit in the bottom of which the lines of stress gather to a point of greatest stress which leads to the above mentioned thickening of the ulna. Some weeks later the reconstrcution zone begins inside this thickening. In connection with springy marrow nails no such accumulation of tension at a point occurs, as mentioned above, but the stress is equally divided on account of a semicircular bending of the springs. As H. BADE (6) and the author were able to demonstrate, this thickening of the ulna can be completely prevented by an intesive X-ray treatment. In this case no reconstruction zone is seen but a typical fatigue fracture (Dauerbruch - Frmuedungsbruch) occurs. The effect of the X-ray treatment seems to be due principally to the damage of the vessels.

The histological pictures of such thickenings of the ulna caused by an overstrain are in a really amazing way similar to the changes caused by the springy blades in the marrow cavity. Exact histological pictures can be derived from GRIFFENSTEIN and RIX(3). In addition the regular structure in the cross section is astonishing. The specific osteogenic layers of the periosteum begin to grow exuberantly. The resting periosteum, which is poor in cells, forms by a rapid mitotic division a broad area of germinal centers or an internal layer of germinal cells out of osteoblasts. These produce an osteous like substance without calcium into which the osteoblasts are taken up so that they are depositing small particles of bone by the time calcification begins. The bone from the periosteum promptly unites with the old cortex in a radial direction. It embraces the blood vessels of the periosteum which by this process are shifted into the newly formed marrow spaces. The newly formed marrow cavity is lined with a single layer of epithelial-like cuboidal osteoblasts. However, the formation of endosteal callus is considerable and corresponds exactly to the observations in our experiments.

With regard to the X-ray findings there is also a complete accord. The development of endosteal callus should as well be observed. The beginning cloudiness of the outer margins of the cortex and the appearance of spotted and striped clarifications gives exactly similar pictures. (Ill. 6)

The formation of callus occuring at some distance from the fracture site during marrow nailing are exactly like those seen in the above mentioned experiments. In some cases of a piling up of callus we have to deal with a clearly marked area, 1 to 2 millimeter broad and free of calcium, between the accumulated callus and the cortex. Most often, however, thick masses of callus have piled up immediately next to the bone. This fact cannot be compared with the formations of callus occuring in the marrow space, especially those at the end of the nail. According to the above mentioned experiments there is obviously no doubt that the periosteal accumulations at some distance from the fracture site arise because of the mechanical irritation of the nail. The marrow nail is V-shaped in cross section and the free edges are compressed by driving it into the marrow cavity. The constant pressure of these free edges of the V-shaped nail brings about the mechanical irritation.

The above mentioned spring blades were manufactured of forged V2A-steel as well as of chrome plated steel. V2A-steel had only a slight spring power. As numerous preliminary experiments have demonstrated, this material did not develop any recognizable chemical effect in the marrow cavity so such an effect may be disregarded. The chrome plated steel springs had a greater spring power. By driving them in, however, the danger of some damage to the chrome plating existed so that strong chemical effects might arise. In fact it has been proven to be true that these chemical effects also cause the same irritations. A thin wire of iron or a piece of nickel plated bone saw are sufficient to cause this callus irritation in the above mentioned order (Ill. 5).

Ill. 5 could not be reproduced because the negatives were no longer available.

It is astonishing in this case to observe that at those places where the wires come next to the cortex the greatest accumulation of callus will be found. This can be most clearly demonstrated by the use of zig-zag shaped wires. In this case a chemical effect exists which is in relation to the position of the metal in the electromotor series (the more rare the metal, the weaker the effect) and which is strongest when two different sorts of metal are in use, as for instance nickel and iron. More rare metals like chrome or copper do not show these effects. The latter one even brings about areas of resorption at the place where it enters into contact with the spongiosa and the head of the tibia. Probably this is dependent on the toxicity of the copper ions. This appearance is probably caused by the presence of metal ions and not by the shift of a concentration of hydrogen ions. This can be very nicely demonstrated by brining such foreign bodies into the marrow cavity at equal distance from the endosteum and observing that more metal salt is delivered to one side. This is shown when a saw is driven in, for much more callus can be seen on the side of the bone next to the toothed edge of the saw (Ill. 6).

Illustration 6

I do not regard any further discussion necessary concerning the question as to whether or not the above mentioned changes should be considered under the heading of the origin of callus. Judged by the time required for these changes, the X-rays and the histological pictures, I think there is no doubt that we are dealing with the same changes which we have seen arising following a bone fracture. W. MUELLER also mentioned the above mentioned thickenings of the ulna as callus without fracture.

Finally we know about the formation of callus arising from subperiosteal hematomas, especially on a child's skull and on the tibia, This callus is exactly limited to the extent of the hematoma. No distant effect can be seen in this case.

Some cases of periosteal accumulations and similar changes arise subsequent to certain processes in the marrow cavity such as in the case of a tumor. This should be understood as having been caused by similar chemical or mechanical irritations as those producing the changes cited in the above mentioned experiments. With the springy narrow nail, or still simpler with the irritation wire, we possess in each case a means which enables us to produce tremendous masses of callus such as can be accomplished with no other means. By this irritation the bone is in a certain measure awakened from its resting condition and is stimulated to an immense exuberance of cell growth. This procedure appears very simple and safe and there is no need to expose the bone to a great extent but there is only a metal rod percutaneously driven into the marrow cavity, similar to the marrow nailing. This method appears quite safe, as in none of the experiments did the callus fail to form. The above mentioned method seems to be especially suitable for cases of a delayed healing of fractures and for the treatment of pseudarthrosis.

In addition a remarkable insight into the events of the process of callus formation is gained. The bodies causing the irritation are lying in the marrow and therefore the bone seems to be encouraged to form callus. This would seem to agree with the opinion of BIER who regards the principal influence to be due to the marrow. Thereby the marrow would be expected to have an influence on the callus, similar to the "organizor" of SPEMANN. On the other hand, the clearly recognizable fact is striking

that the nearer the irritation wire is to the endosteum or the cortex the stronger is the formation of callus, This can be easily explained. If one takes it for granted that the irritation of a round wire effects all sides equally, the irritation must reduce in the cross section proportional to the square of the distance. This can be proven rather exactly by numerous X-rays. We are therefore dealing with one of those cases where the biological process may be expressed in numbers. This means that in such a method of callus formation there is something completely regular which can always be repeated in the same way. With this mathematical proof that the irritation extends from the wire equally to all sides, there is, on the other hand, nothing said about the kind of irritation and its mode of operation. Concerning the above, there are five possibilities:

1. Electrical lines of force can have the same distribution.

2. A hormone produced by the marrow cavity could in a similar way diffuse equally into the area, although this does not appear a very likely explanation. In this case, MARTIN's declaration, in which the thickening of the ulna towards the place of resection is characterized as sympathetic and is explained by the influence of the overflowing hormone, would be proven to be true.

3. An irritation of the cells extending from the marrow cavity could have the same distribution. In the nerveless bone substance these bone cells with their extensions would act as the irritation conduit which, according to PETERSEN, are the only irritation conduit system of the bone.

4. A chemical irritation arising from the wire, like a metal salt for example, could diffuse to all sides from the wire and stimulate the periosteum to form callus.

5. The bone substance is irritated either by the pressure of the spring, lying in the marrow cavity,or by the chemical effect of metal salts and it either begins to form callus or stimulates the periosteum to form callus.

The first possibility can be most easily excluded by giving the electric lines of force a special direction. The most simple way to obtain this is to bend the wire at the place where it extends out of the bone and to stick the bent end downwards through the tissue so that it lies close to the bone from outside. In none of the experiments could such an influence of the bent wire be proven. The fact that there is really a hormone formed in the marrow cavity appears extraordinarily unlikely to me. As long as 18 months ago, during the first marrow nailings, I observed that "little hats" of bone substance were formed on top of the heads of the nails rising out of the bone. The only explanation for this formation of the "little hats" is that there are some drops of fat running out of the marrow along the channel of the nail and this stimulates the bone formation when it comes in contact with connective tissue. In the histological picture these "little hats" show bone tissue containing thick connective tissue components. (Ill. 7). Also cartilaginous pre-formed bone is forming in this case. By experiments with injections the cell-like parts of the marrow can be excluded. All this indicates

that a fat soluble hormone plays a part in this process. This will be discussed later.

The marrow fat is also capable of stimulating the periosteum to form callus. These various kinds of callus can be demonstrated in experiments without a fracture. The fact that the marrow is of importance during the healing of a fracture, of a bone seems certain to me. On the other hand the marrow is of no importance in the experiments we are dealing with. The masses of callus also arise in the same form and with the same rapidity by the irritation effect of wires, etc., if one completely currettes out the marrow and the periosteum, an operation easily possible from the top of the trochanter.

Illustration 7

In any event we know, because of WALTERSHOFFR's and SCHRAMM's experiments (7), concerning the demarrowing of the human bone in pernicious anemia, that the marrow regenerates with extraordinary rapidity. A fortnight later, however, by which time certainly not much marrow can have regenerated, an extraordinary amount of callus can be seen in the X-ray. The destruction of the marrow alone, a process during which a large quantity of hormone should be freed, does not in the least cause this appearance. Finally two dogs were used for these experiments. Their marrow cavities were completely filled with drilling wires of V2A-steel or glass rods. Their bones did not show any changes for one year. Finally, the non-irritating V2A-steel and the glass rods were replaced by zinc plated wire of iron. Immediately a tremendous formation of callus began. The fact that marrow is not necessary to cause this peculiar process can finally be proven in a very simple way: If the marrow cavity is - as above mentioned - filled with as many wires of V2A-steel as can be put into it, no callus will be formed for neither a chemical nor a mechanical irritation arises. On the other hand, if a thicker rod of V2A material is driven into the middle of the bundle of wires adequate callus will form, for in this case the marrow cavity is kept under a constant pressure on accout of the elasticity of the bone tube.

The possibility that the periosteum is irritated chemically or by a wire lying in the marrow cavity is conceivable. On the other hand, we know on account of our daily experiences that metal splinters situated outside the bone at a moderate distance from the periosteum are not capable of stimulating it to increased callus formation. Certainly callus can be produced by the introduction of metal between bone and periosteum, especially by using magnesium, as NOGORA was able to demonstrate recently. These callus formations, however, do not in the least approximate the above mentioned reaction. Furthermore, it can well be taken for granted that the mechanical irritation reaches the periosteum right through the bone. The stretching of the periosteum thereby obtained is exceedingly small. On the other hand the existance of the periosteum is absolutely necessary for the realization of this process. In a series of experiments on younger and older dogs, the periosteum of their bones was stripped off or scraped off for an area of 2 to 3 centimeters. In this area the process mentioned before failed to occur in all cases. The fact that the nourishment of the affected area of the bone would suffer so much by this removal of periosteum that the failure of the above-mentioned process could be explained on this basis does not seem very likely to me as the interruption of the nourishment seems to be too small. Furthermore the above mentioned histological pictures clearly stress the fact that this new bone is only formed by the periosteum. After all this, there is only one explanation possible, namely the one according to point 5 that the bone substance itself is mechanically or chemically irritated and that the bone substance then stimulates the periosteum to form these tremendous masses of callus. In this case the question is still not clarified as to whether we are dealing with a direct irritation of the cells, an influence on the vessels of the periosteum or if a special pouring out of "callus hormone" takes place. According to the above mentioned experiments with X-ray treatment an influence on the vessel seems to be very likely.

The formation of callus in the ulna of a dog, which is in every respect the same process, is also caused by a direct mechanical irritation of the bone substance on account of an increased mechanical strain in the area next to the place of resection. This callus formation as well as the thickening arising during the experiments with marrow springs should be regarded as a functional hypertrophy. The above mentioned experiments permit an interesting insight into the mechanism of this process.

In my opinion the knowledge gained can undoubtedly be applied to the events arising during the healing of a bone fracture. After all, in this case as well, the irritation of the bone substance is the most essential thing. The irritation at the time of the trauma seems to be sufficient. On account of the interesting examinations of HAASE (4) we know that in the area surrounding the fracture there are zones of the most pronounced mechanical injury, the so-called "confusion zones". The irritated bone substance later stimulates the periosteum as well as the endosteum to form callus. Similar marked irritation of the bone substance can be obtained by the drilling method of BECK, the sawing method of BRAND or the splitting method of KIRSCHNER. Without this irritation the periostum is not capable of producing sufficient quantities of periosteum. This agrees with the experiments of the transplantation of periosteum. Transplanted periosteum of older animals does not form any bone. The part played by the marrow

is also clearly defined. The marrow substance stimulates the periosteum or the connective tissue to from bone wherever it enters into contact with them. The marrow cavity is thereby constantly separated from its surroundings.

The further destiny of the callus is determined by the mechanical circumstances at the place of fracture. Bone is a structure exposed to constant pressure. In such a structure there are always drawing froces opposed to the pressing forces. The position and course of the cleft of a pseudarthrosis is determined by extremely strong drawing forces or pushing forces plus shearing effects.

The experiments described seem to me to be especially suitable to clarify the differences of opinion between BIER and LEXER concerning the formation of callus. These experiments agree with the opinions of numerous other authors who regard the bone substance itself as being far more important in the case of a fracture. Thes experiments agree with the findings of O. MAIER who has observed an increased callus formation in cases of fractures where a pin of magnesium was driven into the fracture cleft.

The experiments are of practical importance in that they represent a justification of the procedure of marrow nailing. The marrow nailing therefore seems to be especially suitable in cases of badly healing bone fractures and of pseudarthroses. Callus whic can be produced in excessively large quantities seems to be the desirable material for bone plastic work.

Finally a warning must be given not to cause any damage to the periosteum in cases of a bone fracture. Especially the separation of the periosteum from the bone should be avoided if at all possible.

S U M M A R Y

The long tube bones of dogs were exposed to a strong pressure by springs of V2A-steel precutaneously driven into the marrow cavity. Thereby enormous thickenings of the bone are caused which are of connective tissue nature and which, even in details, exactly corresponds to the functional hypertrophy arising in the ulna after a resection of the radius. The same changes can also be caused by the chemical irritation of thin wires driven into the marrow cavity. We have to deal with enormous masses of callus which are, as demonstrated formed by the periosteum only. In this case, however, the callus is formed in sort of an indirect process by an irritation of the bone substance. The marrow is capable of stimulating the periosteum and the connective tissue with which it enters into contact to form new bone. The above mentioned experiments give remarkable insight into the procedure of the functional reconstuction of bones and the formation of callus in cases of a fracture of the bone. They also seem to be of practical importance for the treatment of bone fractures and pseudarthroses as well as for bone plastic work.

B I B L I O G R A P H Y :

(1)	W. B L O C K	Neue Deutsche Chirurgie
(2)	A. W. F I S C H E R	Chirurgenkongress 1940
(3)	G R E I F E N S T E I N and E. R I X	Marburger Sitzungsberichte (1929)
(4)	W. H A A S E and G. R I C H T E R	Arch. Orthop. Chir. 193[illegible]
(5)	G. K U E N T S C H E R	Chirurgenkongress 1940
(6)	B A D E	Fortschr. Roentgenstr. 1939
(7)	W A L T E R H O F F E R and S C H R A M M	Arch. Klin. Chir. 1922

THE IMPORTANCE OF STIMULATING THE MARROW-CAVITY TO THE HEALING OF NAILED FRACTURES

by

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With 31 Illustrations*

* Illustrations 1,2,3,5,7,8,10,11, 20,21,23,25,26,29, are microscopic views which could not be reproduced.

Translation prepared by:

U. S. Naval Technical Unit, Europe, (Medical Section)
Office of Naval Advisor
Office of Military Government (U. S.)

When KUENTSCHER described his method of marrow nailing at the German Surgical Congress in 1940 objections were made to the introduction of so large a foreign body into the marrow cavity (NORDMANN, KOENIG). In particular it was believed that the growth of callus might be disturbed.

KUENTSCHER in refuting this criticism stated that in addition to other factors favorable to the growth of callus the very presence of the nail had a stimulating effect. He based this statement on the results of his own experiments.

By introducing stimulating bodies into the marrow cavity KUENTSCHER succeeded in causing "callus without fracture". A nickel plated iron saw and a zinc plated iron wire introduced into the marrow cavity of a sound bone caused an enormous thickening of the long bone. This increase of thickness was due to the formation of periosteal callus tissue. A similar though not equally extensive periosteal reaction occurred when KUENTSCHER tried to bend the bone by means of a strong leaf spring. No bending, but the aforementioned thickening of the bone resulted. Also the power of pressure exerted by a strong spreading nail or by several metal bars of V2A steel forcibly driven into the cavity, caused periosteal formation of callus. KUENTSCHER concluded that the very bone substance is stimulated chemically or mechanically and that it is this bone substance which causes the periosteum to form this enormous amount of callus. Whether there be a direct cellular stimulation, an influence on the periosteal blood vessels or the secretion of a special callus hormone - this question remained unanswered. The extent of the reaction is directly dependent on the extent of the stimulation. KUENTSCHER said that with the stimulating wire we are given the possibility of creating enormous masses of callus. "The bone is wakened out of its rest by this stimulation". He calls the young bone tissue the "os activum".

In accordance with these experimental results KUENTSCHER found in some nailed fractures periosteal callus formation throughout the whole length of the nail so that the nail was regarded as a stimulating body, either mechanically or chemically.

This description cannot but induce the tempting idea to increase the growth of callus by stimulating the marrow cavity thus achieving a more rapid bony union of the fracture.

I must admit that I myself for a long time pursued this idea and have tried to find out by numerous experiments the "most suitable" stimulants of the marrow cavity to be used in addition to the nail. But the results of these experiments turned out quite different from what I expected and made it absolutely necessary to clarify the following questions:

1. What are the conditions effecting the growth of callus after stimulating the marrow cavi-

ty? Is damage inflicted thereby upon the bone?

2. Does the development of this callus, formed by the periosteum, depend on the age of the individual?

3. Are the changes in the bone caused by the irritation of the marrow cavity completely reversible? What is the final result of such a process?

4. Finally, it seems advisable to try to investigate by comparable experiments whether the periosteal growth of callus caused by an additional stimulation of the marrow will also mean a more rapid bony union of the fracture.

1. What are the conditions effecting the growth of callus after stimulating the marrow cavity.

Studying the literature with regard to this subject, I noticed that the question of the reaction of bone to a stimulation of the marrow cavity, which has recently regained considerable importance by marrow nailing, has been of intense interest in former times.

In 1775 TROJA intended to produce necrosis of the bone by introducing a red-hot wire into the medullary cavity of a dog's bone. He did not succeed. He only observed an increasing thickening of the whole bone during the following weeks.

Later on BICHAT got the same result.

The nature of this thickening of the bone we learn from F. BUSCH who continued these experiments a hundred years later. Recognizing that the damage inflicted upon the marrow by the introduction of the red-hot wire is not sufficient, he heated a platinum or iron-wire by a galvanic current and pulled it through the medullary cavity which he had drilled open at both ends. Depending on the duration of the heat applied he could distinguish 4 different degrees of reaction of the bone:

1° : no necrosis, only marked inflammations (osteitis)
2° : death of the central layer (necrosis centralis)
3° : penetrating necrosis, eventually total necrosis
4° : death of the whole bone and eventually of the soft parts as well.

He found the first degree 3 times among 26 dogs. He killed the animals on the 53rd, 67th and on the 73rd day.

The "pure osteitis without necrosis" described by him corresponds to our "formation of callus without fracture".

In 1878 BUSCH irritated, or rather damaged the marrow in another way. Again he opened the medullary cavity by

drilling it at both ends. He first destroyed the marrow with a thick iron wire and then he pulled a cotton wick through the cavity. He soaked this cotton wick with different fluids. Proceeding in this manner he avoided forcing the active substance into the blood-stream and into the circulation. His experiments with a mixture of turpentine and oleum sinapis are described most precisely. The reaction of the bone differed according to the quantity of the active substance applied which was varied by the length of the wick and by the speed with which it was pulled through the cavity. Again he describes the typical picture of "callus without fracture". After 30 days the tibia showed an extensive thickening by considerable formation of periosteal callus.

1877 BUSCH announced the remarkable fact that in controlled experiments with indifferent foreign bodies, for instance platinum wire, no reaction of the bone was to be observed, a very important result with regard to our present point of view on these experiments. (Illustration #1 demonstrating the "pure osteitis" of BUSCH (1877) made from an illustration of the original article, could not be reproduced with the available facilities.)

1878 BUSCH produced the necrosis of bone by placing in the medullary cavity a bar of laminaria which would swell. But not in all cases did he succeed in causing necrosis. In 7 cases he obtained necrosis, in 3 putrefraction and in 3 cases "pure osteitis", the latter showing again the picture of a extensive formation of periosteal callus. The swollen laminaria bar lay firmly pressed into the medullary cavity and the bone was completely encircled by a thick layer of newly formed callus.

1879 KOCH caused necrosis of bone by injecting mercury into the arteria nutritia of the tibia of a dog. He explained the necrosis as having been caused by emboli. When using only very small quantities of mercury he did not observe necrosis but a marked "periostitis" which he also believed to have been caused by embolic disturbances of nutrition. In the macerated preparation prepared when the dogs were killed some weeks later, he found very small balls of mercury still present in the marrow and in the corticalis. While from the report of this work we cannot conclude that we have once again the phenomenon of extensive growth of periosteal callus we are able to see this with certainty from the following experiments.

In the same year BUSCH made further experiments with the same technique. His results were as follows:

$\frac{1}{4}$ of a "Pravaz-syringe" of Liqu. ferri sesquichlor. causes putrefraction of the leg of a sturdy dog. The bone was dyed black by the iron salt.

$\frac{1}{2}$ of a "Pravaz-syringe" of undiluted carbolic acid produced a large tubular secuestrum but no callus.

1 "Pravaz-syringe" of putrid-fluid (pieces of muscle with blood serum) caused slight formation of periosteal

callus near the foramen nutritium. The inflammatory signs were slight in the first days and soon subsided.

½ "Pravaz-syringe" of mercury caused putrefraction of the whole leg, with total necrosis of the bone.

1-2 grams of mercury caused a spindle-shaped thickening of the tibia which slowly increased in the course of 3 months. Again the author described the "pure osteitis" the typical picture of development of "callus without fracture". Again the young bone was clearly demarcated from the old corticalis. In this experiment the same formation of callus was found by the author in the marrow cavity for the full length of the bone. The marrow cavity was filled almost completely by callus. In [illegible]'s opinion the explanation of this phenomenon by mechanical reasons as given by KOCH neither seems sufficient nor satisfactory. He believed in a chemical influence of the mercury.

For completeness it must be mentioned that at several places in the literature I have found reported that DIEFFENBACH during experimental studies had put foreign bodies into the bone, iron as well as others, and that he had observed an inflammation and thickening of the bone by growth of callus. To my regret I have not succeeded in locating these publications of DIEFFENBACH. The literary references given by the other authors are not correct.

The results of these interesting experiments and particularly the explanation given by the above authors can be understood only if we consider that they were made before the "aseptic area".

Generally they had been aimed at the exploration of the disease today known as "suppurating osteomyelitis". In ignorance of the causative part of the pyogenic microbes the authors believed that only the degree of the irritation was responsible for causing "necrosis of bone with formation of sequestra" in one part of the cases while in the other part "simple osteitis" with thickening of the bone was to be observed. Today we know that we have to separate the "pyogenically infected necrosis of bone" frequently accompanied by the formation of sequestra, from the "simple or aseptic necrosis of bone". The experiments of BUSCH are to be regarded as a classical example of the "aseptic necrosis of the bone" with its impressive stimulating effect on the surrounding bone-forming soft parts. (AXHAUSEN and BERGMANN).

This "aseptic necrosis of the bone", then called "simple osteitis", is characterized by the fact that the bone will react to a considerable variety of stimulations exerted from the marrow cavity with the same response, namely an abundant formation of periosteal callus. Suitable stimulating substances are etheral oils, heat, and pressure acting on the interior of the long bone.

Now the question arises whether or not the "callus without fracture" (KUENTSCHER) is due to a necrosis of the bone. I have concluded that it is as a result of the following experiments.

Illustration 2 shows the transverse section through the tibia of a guinea-pig 6 weeks after the introduction of a cotton wick soaked with gold chloride. The old corticalis is surrounded by a layer of periosteal callus which in some areas is far thicker than the old cylinder of bone.

In some areas the old corticalis is eroded away by the inward growth of the newly formed bone arising from the periosteal callus. Lacunae have appeared in a broad line in the outer layer of the old bone, while no changes at all appear in its central layers. (Illustration #2 could not be reproduced with the available facilities.)

Illustration 3 shows this process well advanced. This is the tibia of a guinea-pig into which some drops of mercury were installed 5 weeks previously. Only one segment of the old corticalis is left. Its contour is bizarre and indented. Everywhere sharply outlined lacunae are to be observed where the destructive young osseous tissue is intruding into the old bone. The structure of the old bone has not changed. (Illustration #3 could not be reproduced with the available facilities.)

Illustration 4 shows approximately the same stage in a roentgenogram. Encircling an irritating iron bar the old corticalis is situated as a thin sequestrum surrounded by a thick cover of callus which appears like a kind of involucrum.

Illustration 4

Central sequestrum in the "involucrum"

Illustration 5 gives an insight into this process shortly before its conclusion. It shows the transverse section through the tibia of a guinea-pig 8 weeks after a V2A-bar covered by a thin layer of a lunar caustic was inserted into the marrow cavity. At the internal margin of the new bone cylinder, which is built with marvelous radial regularity, remnants of the old corticalis are still to be recognized as sharp lines. (Illustration #5 could not be reproduced with the available facilities.)

Also in the roentgenogram (Ill. 6) small remnants of the old bone containing greater amounts of bone salts, are still clearly visible as narrow longitudinal lines in the interior of the new bone.

Illustration 6

The old corticalis is removed except for slight rests

The cases mentioned show quite clearly that total necrosis of the corticalis resulted from the irritation of the marrow cavity. The necrosed bone is destroyed and removed by the new osseous tissue formed by the periosteum.

But not always is the process so impressive and I understand quite well why BUSCH spoke of an "osteitis". Illustration 7 shows the tibia of a guinea-pig, 20 weeks after the introduction of a zinc coated iron bar. We find the typical picture of the lacunary resorption of the bone in the old corticalis increasing in the direction from cortex to center. The periosteal callus envelopment is evidently older, corresponding to the longer duration of the experiment. There is only a small number of connections between the young and the old bone by Haversian Canals.(Illustration #7 could not be reproduced with the available facilities.)

The latter have developed in a considerably greater number in the right tibia of the guinea-pig (Illustrated in Illustration #8 which could not be reproduced with the facilities available) in which also a zinc bar had been inserted 20 weeks previously. Here too the periosteal callus tissue shows distinctly the structure of the final bone. The majority of the numerous spaces of resorption and so-called osteo-genetic centers run from cortex to center in a radial direction. Besides, the structure of the corticalis has not changed it shows no signs of death of the tissue. Yet we know quite well how long dead bone may preserve its structure and its capability to absorb colors (staining characteristics). Moreover we can conclude from these pictures that an inner reformation, an inner "substitution", became necessary. The question whether there is a necrosis or an aseptic inflammation taking place remains unanswered. At any rate the essential fracture of the formation of "callus without fracture"

appears to be a destruction of the corticalis (necrosis or inflammation). In order to support this damaged corticalis the bone reacts by the formation of periosteal callus. How will the latter take place and what will be its causative factors?

From the roentgenogram Illustration 9, we can learn these factors quite easily. It shows the femur of a 2½ year old dog in which a thick rusty iron wire had been inserted 8 weeks previously. The wire extended to somewhat below the middle of the bone. At the back side in the middle of the shaft we saw a complete distruction of the corticalis (Illustration 10). Encircling this center of destruction a thick cover of periosteal callus has formed in such a way that the destroyed part of the corticalis is situated nearly in the middle part of the callus. This supporting cover extends far beyond the irritating foreign body, the point of which is lying in its center, at the area of the most thorough destruction of the corticalis which acts as a notch in the bone cylinder. The form of the covering callus is adapted to its functions. At the front side of the bone, which is at the same time the convex one, where the tension and power of traction act the callus is thin covering the corticalis like the skin of an onion. At the concave side where the stress of compression is acting it is broad and piled up serving as a console (supporting structure). We learn from this picture that the location, extent and shape of the periosteal callus is not directly dependent on the chemical stimulation but rather depends on the location and amount of destruction of the corticalis which has to be supported. (Illustration #10 could not be reproduced with the facilities available.)

Illustration 9

Femur of a 2½ year old dog, 8 weeks after introduction of an iron wire. Extensive center of destruction in the corticalis.

Such a support being unnecessary we shall miss the periosteal callus reaction as shown in Illustration 11 and 12. In the first we have the tibia of a two year old dog which was subjected to the application of heat in the marrow cavity. We must take for granted that during this heating an unavoidable minimal amount of necrosis of the central corticalis occurred. This is proven by the transformation taking place in this layer at least on the one side accompanied by endosteal formation of callus. In the periosteum we find no sign of the least reaction. If the "formation of callus without fracture" actually is caused by a "necro-hormone" (BIER) as well, it would certainly have caused a periosteal reaction here. But since the statics of the bone cylinder have not been impaired there was no reason for a periosteal reaction. The same can be said regarding the roentgenogram Illustration 12. In the neighborhood of an irritating iron kernel of considerable length which was installed beside a nail of V2A steel in the tibia of a dog we found, 16 weeks later, a distinctly visible area of increased permeability to X-rays. Here the central layers of the corticalis are destroyed and removed and yet there is not the least periosteal reaction. (Illustration 11 could not be reproduced because the negative was not available.)

Illustration 12

Central area of destruction by iron kernel, 16 weeks after insertion. No formation of periosteal callus.

Remembering the fact that a stress of the bone tending to bend it (caused for instance by leaf springs) or an increased internal pressure (cause for instance by laminaria or spreading-nail) will lead to the formation

of a strong periosteal prot ctive cover we may conclude that the essential feature of "callus without fracture" is to be found in a change of the corticalis, namely of its physical circumstance. These changes can be brought about either mechanically (by spring, laminaria, nails) or by a necrosis or inflammation of the bone caused by thermal or chemical influence.

Now we shall find no difficulty in giving an explanation for the d velopment of a periosteal cover "reaching far beyond the area of the fracture" frequently observed clinically and described by GRIESSMANN and REICH in its microscopic appearance. Since V2A nails have been used which in the absence of a fracture never will cause the formation of callus, there can only exist mechanical reasons for it. Let us compare the nailed fracture of a marrow bone with two tubes of a similar diameter which have been united by a bolt driven into them. This bolt will prevent the unity of both the tubes and the bolt inside from being angulated. Doing so the bolt has to exert a lateral pressure on the inside of the end of the tubes and this pressure will become the more intense the nearer we get to the point where the ends of both tubes are united (Illustration 13). In response to this stress the living body tube must produce an encircling callus lest the corticalis should be destroyed by the pressure. The cross section of these prot ctive masses of

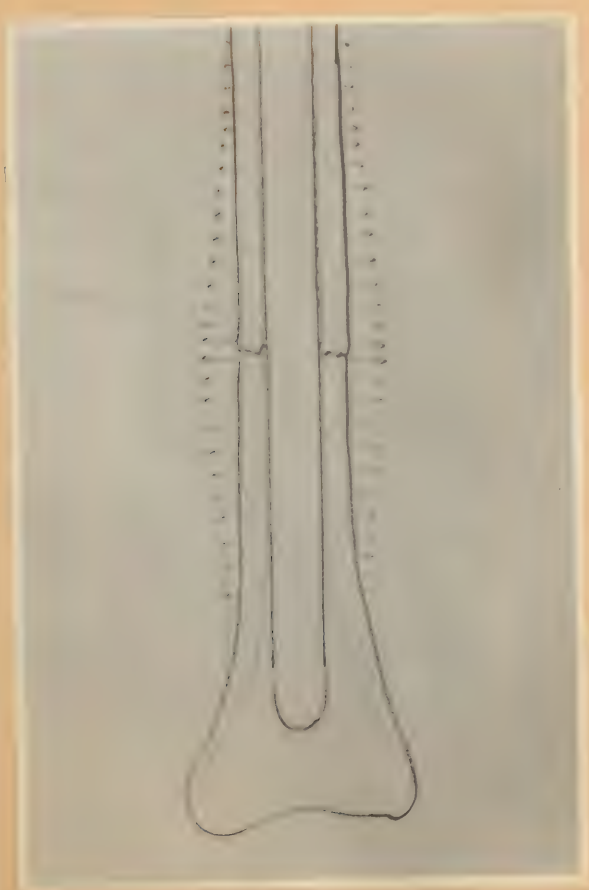


Illustration 13

The arrows indicate the amount of the powers of pressure which are acting upon the bone cylinder of a nailed fracture. The space covered by the arrows corresponds closely to the spindle of callus observed by us.

callus are the largest at the level of the fracture. Thus a spindle-shaped cal us will develop round a nailed fracture even if a chemically inactive material has been used. The arrows indicating the amount of

stress (Illustration 13) will outline a spindle similar to that formed by the callus. This has been observed often in practice. Thus is explained how pathological stress in the tube of the corticalis leads to the formation of a periosteal callus.

I am convinced to have finally proved that the stimulation by an exertion of mechanical strain upon the periosteum is necessary for causing the formation of a periosteal cover by the fact that a piece of tibia when excluded from its physiological tension does not show this reaction. A small piece of bone was resected from the tibia at its proximal and distal end and set out of function by the manner of extension which is to be seen on the diagram. The defect of the bone is slowly bridged over as shown by the later picture; But an extraordinary (-special-) formation of periosteal callus as would have been expected from the stimulation of the marrow is not to be seen in the isolated piece of tibia.

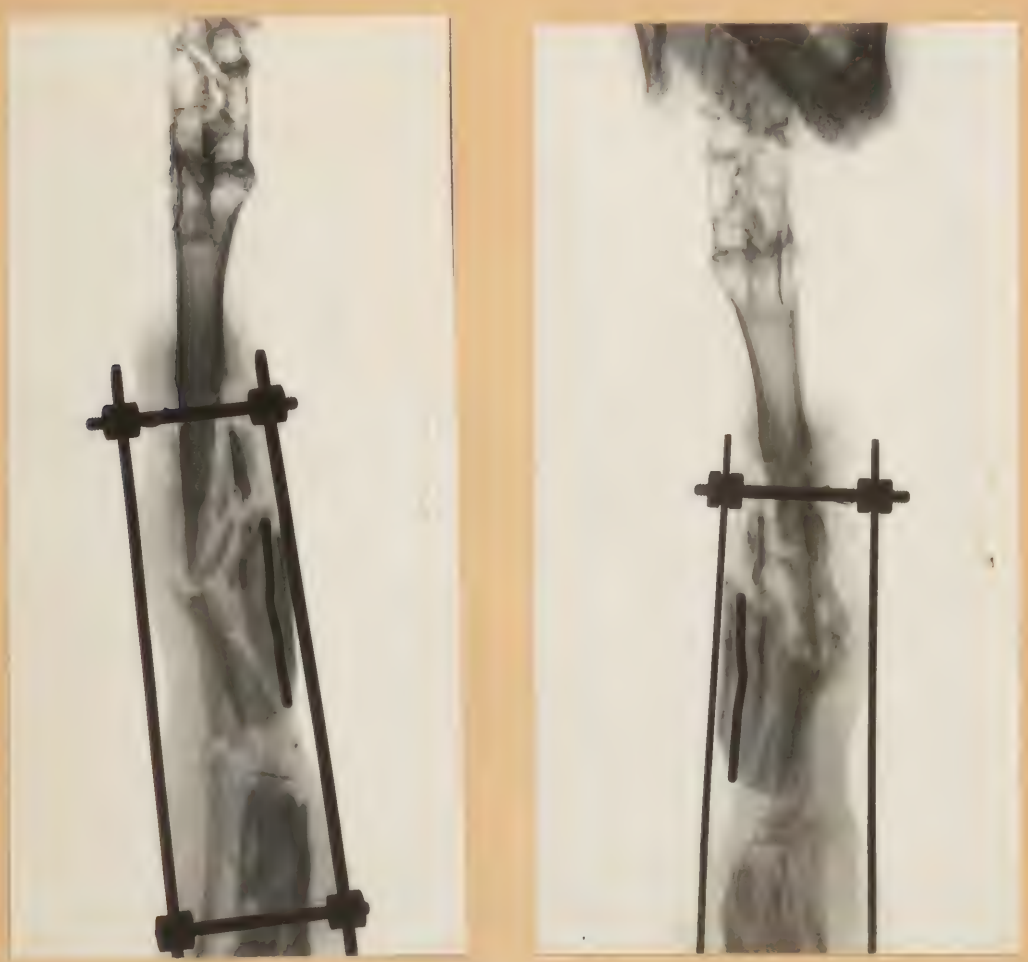


Illustration 14

Missing formation of periosteal callus after stimulation of the marrow (iron) in a piece of tibia being set out of function in a physical sense.
a. 10 weeks after the operation
b. 18 weeks after the operation

2. Does the development of "callus without fracture" depend on the age of the patient?

The reactive capability of the periosteum being of fundamental importance for the formation of periosteal callus we shall have to examine whether and to what extend this reaction depends on the age of the individual. Here should be mentioned for the first time two clinical experiments which I have made in the expectation that by stimulating the marrow cavity the formation of callus and in consequence also, the healing of the fracture would be influenced favorably. These experiments seem to be justifiable since numerous animal experiments had proved them to be innocuous.

The first case was a 54 year old patient Joh. C. who had sustained a fresh simple fracture of the lower leg. The tibia was treated with a nail covered with a thin layer of zinc in the two middle fourths (15a). During the first weeks a striking warmth of the leg could be observed clinically. The patient complained of a painful throbbing with a feeling of heat. The leg showed all signs of an aseptic inflammation. There was no fever. Six months later the roentgenogram showed an intense "osteitis", i.e. small spotted rarefactions all over the whole bone. But the demineralization was delayed in the area adjacent to the zinc which looks like a central sequestrum (Ill. 15b). The process of this disease lasted for half a year. By then the bone had regained a nearly normal appearance and the patient was able to return to work. A periosteal reaction was not observed at any stage nor did a delay in bony union occur.

Illustration 15
patient Joh.C. 54 years old.

Illustration 15a
Freshly nailed closed fracture of the tibia.

Illustrations 15 b and 15c

b. Central aseptical sequestrum in the area of the irritating layer of zinc on the nail. Porosis of the other bone tissue. No periosteal reaction.
c. Slow restoration of the normal structure of the bone after removal of the nail.

The second case was a 74 year old woman who had received a transverse fracture in the middle of the femur (Illustration 16). Zinc again was used as additional stimulation in the two middle fourths of the nail. Clinical symptoms of aseptic inflammation did not exist. But the roentgenogram disclosed the same changes as mentioned in the case before, namely general rarefraction and the formation of a central sequestrum in the neighborhood of the zinc. Here too no periosteal reaction at all was observed (Illustration 16). A measureable disturbance of bony union was not seen. Slowly the bone regained its normal structure (Illustration 16c).

In both cases we had older individuals and in both extensive changes had been inflicted upon the corticadis caused by the irritation of the marrow cavity and in both cases we can speak of a transient sequestrum-like formation of the central layer of the corticalis. But at no stage of this process did the least periosteal reaction take place. Only a scanty formation of callus at the very fracture, in which the periosteum too may have shared was to be seen.

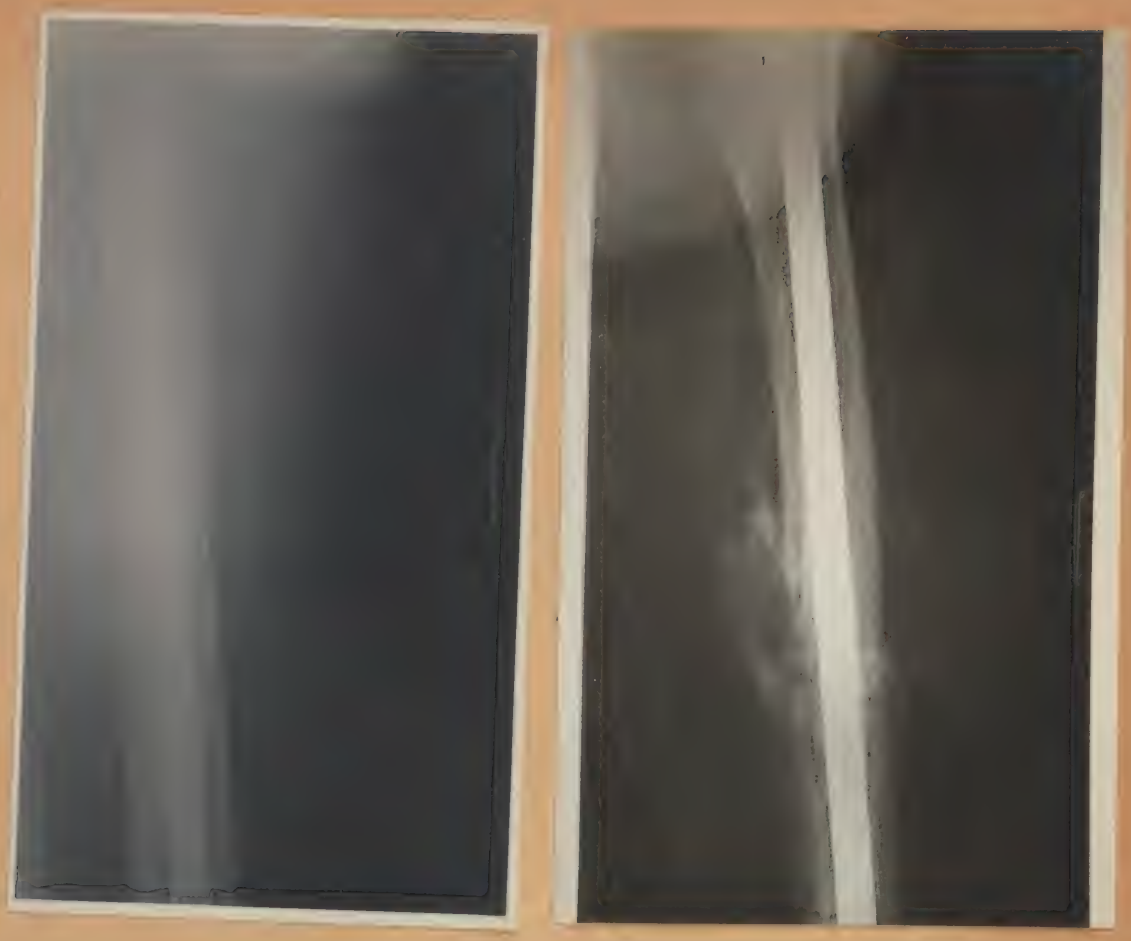


Illustration 16 Patient Ida Z., 74 years

Ill. 16a and 16b

a. Freshly nailed closed fracture of the femur.
b. Central aseptic sequestrum in the area of the irritating layer of zinc on the nail. Porosis of the other bone tissue. No periosteal reaction.

Illustration 16c

Slow restoration of the normal sturcture of the bone after removal of the nail.

Surveying our nailed fractures we found (ALSLEV, GRIESSMANN and SCHUETTEMEYER) that only with younger individuals up to 20 years was a formation of periosteal callus reaching far beyond the fracture itself, to be demonstrated as is shown in Illustration 17 for instance. Also when surveying numerous fractures which had not been nailed we made the striking observation that a spindle of callus, as shown for instance in Illustration 18, is to be observed only with young individuals.

Illustration 17
Extensive formation of periosteal callus throughout the whole length of the nailed radius.
Patient Karl-Heinz L. 18 years.

Illustration 18
Callus spindle of the young in the tibia of a fracture n o t nailed.
Patient Chr. St. 9 years

In accordance with this observation HERZOG met an increase of thickness of the shaft of the nailed thigh only with young individuals. S. ORELL reported on a particularly scanty formation of "os novum" in older individuals. This "os novum" is produced by installing a chip of bone (os purum) under the periosteum. It also agrees with the former observations that transplantation of periosteum alone of the growing animal produces bone (AXHAUSEN and BERGMANN). Finally I mention the publications of SWANTE ANNERSTEN (1942) according to which the periosteal callus chiefly represents a characteristic formation of the young (age below 20 years). He examined

the development of callus in fractures of the diaphysis of the forearm.

In the same year I reported on the chemically stimulating effect of the KUENTSCHER nail. I refer to the formation of periosteal callus extending the entire length of the diaphysis accompanied by a reconstruction of the corticalis recognizable by its irregular condensation and rarefraction of its structure as described by KUENTSCHER. Such a reaction I found in only 5 cases and always only in young individuals of less than 20 years. It was probably caused by a not entirely corrosionproof steel as was used for a short time before employing V2A-steel.

Animal experiments showed the same conditions. In Illustration 19 we have the tibia of a 10 year old dog, 7 weeks after installing a strong irritation of the marrow cavity (namely two zinced iron wires). We observe only a very poor periosteal reaction at the back side of the bone where the corticalis is damaged by the closely adjacent iron wire. This damage may be seen in the microscopic picture (Illustration 20, the microscopic picture of illustration 19, which could not be reproduced because the negative was not available.)which shows that we have again principally the same process we have found before elsewhere. But on comparing the callus reactions the difference is only one of extent.

Illustration 19

Poor periosteal reaction of a 10 year old dog, 7 weeks after introduction of two zinc coated iron wires.

The microscopic picture (Illustration 21) shows the tibia of a senile guinea-pig 20 weeks after installing an iron-zinc bar. Large spaces of resorption in the corticalis prove the necessary reformation of the damaged bone. But the periosteum does not show the least reaction. (Illustration 21 could not be reproduced because the negative was no longer available.)

3. Are the changes inflicted upon the bone by the irritation of the marrow cavity reversible?

Illustration 22 shows the tibia of a dog of about 2½ years old, 4 months after an intense application of heat to the marrow cavity. The central sequestrum which was present 4 weeks after the damage (Ill. 22b) is removed. The transient extensive formation of callus has decreased to a great degree. The border between the old and the new bone can only be guessed (Illustration 22c). The reformation of the bone is not yet complete as can be seen from the large blood containing spaces in the corticalis (Illustration 23) but the bone has already to a great extent adopted its original shape according to the principle of functional adaptability. (Illustration 23 could not be reproduced).

Illustration 22

a. Tibia of a 2 year old dog immediately after cooking the marrow cavity by a heated V2A-bar.
b. Central sequestrum and extensive periosteal reaction 4 weeks later.
c. The central sequestrum has disappeared. A new corticalis has formed out of old and new bone.

The final restoration of the old condition is to be seen from the tibia of dog #6, 2½ year after the introduction of a nickeled iron saw into the marrow cavity.

Neither in the roentgenogram (Illustration 24) nor in the miscroscopical picture (Illustration 25, which could not be reproduced) is any patholocical change of the corticalis cylinder to be found. The saw is so severely corroded that it is broken. It lay in the marrow cavity embedded in a cavity filled with a thick brown liquid. There was no evidence of a connective tissue capsule around the saw as we observed in previous pictures (Ill. 7, 10, 11, 21, 23).

Illustration 24

Tibia of a 3 year old dog 2½ years after the introduction of a strong irritation of the marrow cavity. The tibia shows now again entirely normal structure.

In the marrow itself iron is deposited in large quantities (Illustration 26). (Illustration 26 could not be reproduced.)

4. Does the extensive growth of periosteal callus caused by the irritation of the marrow cavity also mean an acceleration of bony union?

Considering my description of the "callus without fracture" this seems to be rather dubious since we have to put the question: What has the periosteal cover of callus what have the aseptic osteitis or the aseptic necrosis of the bone to do with the bony union of the fracture? I admit that the periosteal callus can play an important part as shown especially by the long spindles of callus in young individuals which can as well be observed without the use of the nail (Illustration 18). But besides that the "callus without fracture" independent of its origin, can only be of no, or only insignificant, importance for the bony union of the fracture. Let us have a look at the roentgenograms of Illustration 27 and 28.

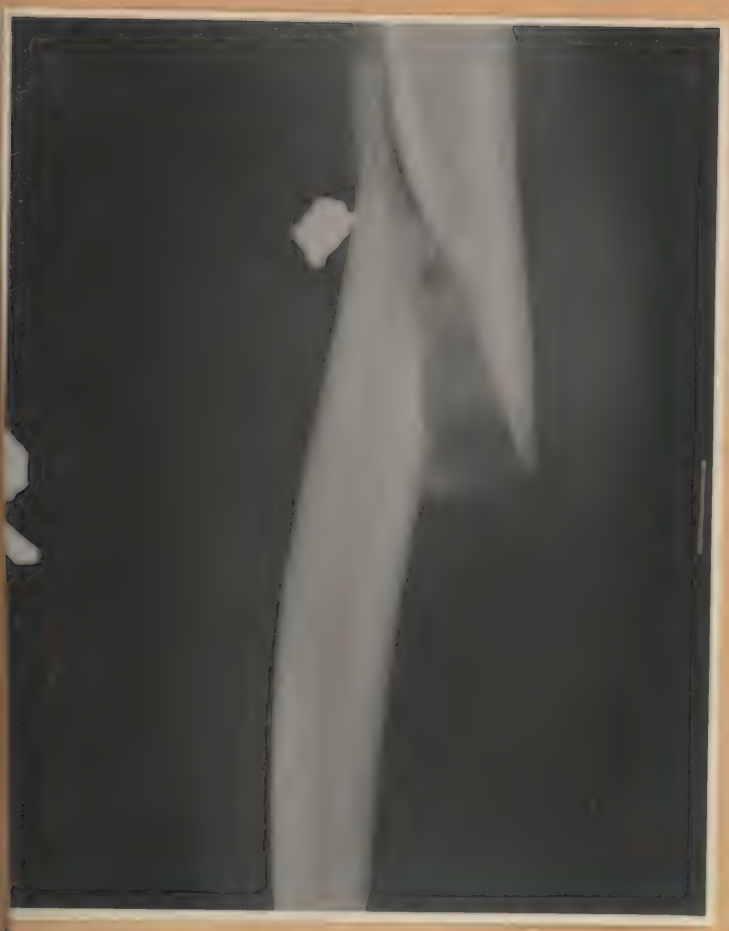
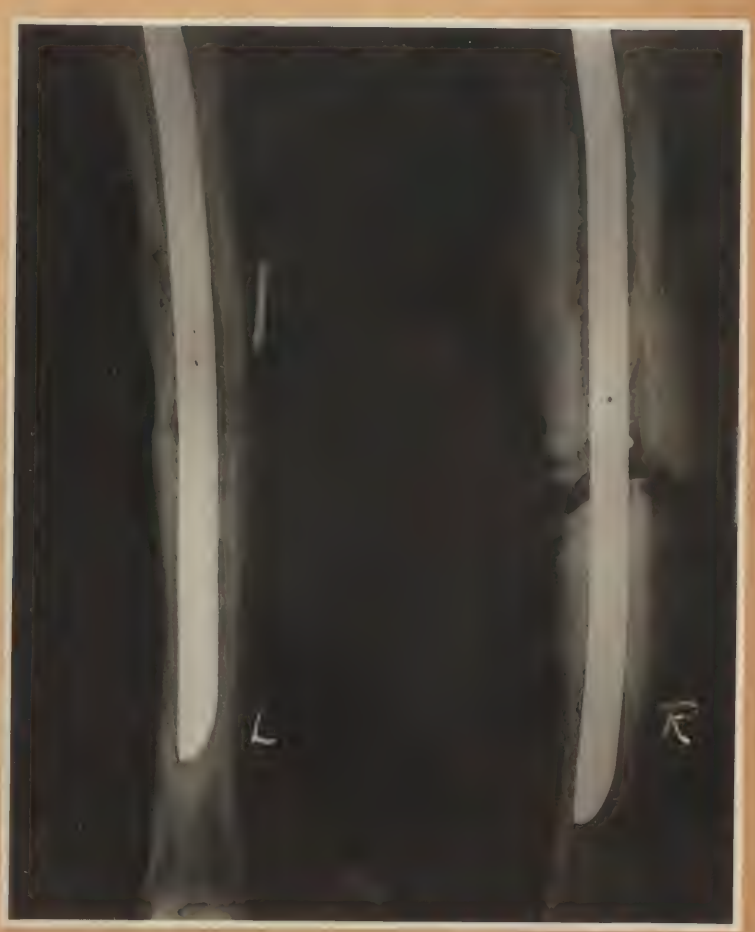


Illustration 27

Purposeful development of intermediary callus in the upper arm. There is nothing to be seen of the periosteum taking part in the bony union.



Ill. 28

Tibia of a dog 32 weeks after osteotomy of both tibiae. The right one is provided with an irritating nail, the left one provided with a V2A-nail left: bony union, right pseudarthrosis in spite of active formation of periosteal callus.

After 4 weeks the closed fracture of the upper arm shows purposeful growth of intermediary callus, filling up the considerable large gap between the fragment. There is no periosteal reaction. The osteotomy of the tibia treated with a zinc coated nail shows the most severe changes of the whole bone with an enormous growth of periosteal callus. Surely the fracture is well stabilized by the nail but the gap between the fragments extends through the callus cover. This callus cover only serves to support the ends of the fragments the corticalis of which is considerably impaired by the aseptic inflammation. This callus has nothing to do with the union of the fracture.

In the clinical experiments (Illustrations 15 and 16) a disturbance of bony union could not be proved. Of course this question is difficult to judge since both fractures were perfectly stabilized by the nail and naturally an early removal of the nail could not be risked in any circumstance. To obtain some certainty I made two further animal experiments. Clarity about this question could best be attained by causing an artificial separation of the fragments - an occurrence which cannot always be avoided even by nailing. Experimental dog #8, 32 weeks after osteotomy of both tibiae doubtlessly shows a pseudarthrosis of the right fracture which had been treated by an irritating nail (iron coat) while the left tibia shows even as early as 6 weeks a good bony union and after 32 weeks a faultless bony healing of the fracture (Ill. 28).

In order to preserve the much more physiological conditions of a closed fracture I have used marrow screws instead of nails. The point of the screw must be shaped like a tap, as otherwise the sufficiently thick screw will burst each tibia. Thus the subcutaneously made and over-extended fracture can be distracted with certainty. The screws installed in both sides were made of V2A steel and the one used for the right tibia was provided with a very long additional stimulating wire and coiled round the threads of the screw. There is a characteristic stimulating quality of the screw even if of chemically inactive material which causes an abundant growth of periosteal callus. This may be due to the mechanical tensions of necessity caused by the screw in the bone cylinder. The formation of the periosteal callus cover was far more extensive on the side of the intense stimulation of the marrow cavity. The lower leg of the dog showed clinically an enormous thickening. Even the soft tissues to a high degree took part in the aspetic inflammation as can be seen from the microscopic picture of the muscles adjacent to the bone (Ill. 29). But together with the aseptic inflammation of the bone accompanied with the intense formation of callus there is to be found simultaneously a distinctly visible disturbance of the formation of callus in the gap between the fragments (Ill. 30) while on the control side this gap was filled up to a great extent with callus. (Illustration 29 could not be reproduced.)

Illustr. 30

Osteotomy of both tibiae Spreading effect by marrow screws. Delayed filling out of the gap between the fragments (right at the side of the irritation of the marrow cavity.

In my opinion this process is not difficult to explain. The disturbing effect of chemically active substances on the growth of callus is known sufficiently well. The clinical and experimental confirmation of this are numerous. Here I want to mention only the detailed investigations of LANGE, KOELSCH and the very interesting observations of Vitro-cultures of J.VERNE, M. MENEGAN, J. M. VERNE and J. B. MAGNANT. A chemically active substance, as for instance iron, causes a destruction of the bone tissue. When this stimulating substance lies far from the periosteum, for instance in the marrow cavity, the periosteum is able to answer with the desired formation of callus. But if the irritating body is situated in the area where the periosteal callus should be expected to develop we will miss this periosteal reaction and only a destruction of the corticalis is effected as shown in Illustration 31., taken from the clinical material. Zinc coated iron wires used for osteosynthesis have caused a complete absence of any growth of callus at the fracture (LANGE).

Since we have to assume that if there is a separation between the fragments the chemically active irritating substances will pass through the gap between the fragments it is not surprising that a disturbance of filling up this gap with callus will occur.

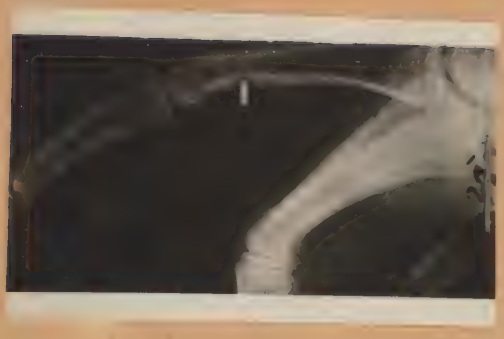


Illustration 31

Area of destruction in the corticalis of a phalanx of a finger caused by iron splinter. The foreign body situated at the surface of the bone prevents a periosteal formation of callus to take place.

SUMMARY

The development of "callus without fracture" is effected by changes of the physical circumstance of the bony cylinder necessitating a support of the bone by means of the formation of this periosteal cover. This alteration of the physical circumstances may be effected either mechanically (by spring blades, laminaria pack, or spreading nails installed in the marrow cavity)or by a chemical or thermal irritation of the marrow cavity causing first a necrosis or an aseptic inflammation of the bone. If it is not necessary to support the bone whose physical circumstances have been altered, the formation of periosteal callus will remain absent or only take place in a very small amount.

The extent of this development of periosteal callus depends on the age of the individual. In youth it is most abundant while in senility it will only appear in a slight extent or not at all.

The radical changes of the bone caused by the irritation of the marrow cavity are completely reversible. When all the reactions have taken place the bone is restored in its old shape with adaption to its functional tasks.

The formation of periosteal callus caused by chemical, thermal or mechanical irritation of the marrow cavity takes place entirely independent of the growth of callus at the very fracture and need by no means be accompanied with an acceleration of bony union of the fragments. The chemical irritation of the marrow cavity can even cause a delay of union or development of a pseudarthrosis.

Therefore it does not seem suitable to provide the nail with an additional stimulant for the marrow cavity since this may disturb the bony union of the fracture. Such a disturbance is not to be expected when chemically inactive material is used. Also for the marrow nail the same rule is to be applied as for all material for bone sutures: It is the more suitable the less it is liable to corrosion.

ALSLEV ..... Inaug. - Dissertation Kiel 1943

AXHAUSEN and BERGMANN ... Henke-Lubarsch IX/3

BISCHAT ..... mentioned by BUSCH

BUSCH ..... Arch. Klin. Chir. Bd. 20 1877 S. 237

" " " " " 21 1877

" " " " " 22 1878

" " " " " 23 1879

" " " " " 24 1879

DIEFFENBACH .... mentioned by KOELSCH

GRIESMANN and REICH ..... Arch. Klin. Chir. 205 S. 455

" " SCHUETTEMEYER .... to be published

HERZOG .....Dtsch. Zschr. f.Chir. 257 Bd. S. 241(1943)

KOCH ..... Arch. Klin. Chir. Bd. 23 1879

KOELSCH .... Dtsch. Ztschr. f. Chir. 246 Bd. S.641 (1936)

KOENIG .... Chir. Kongr. Berlin 1940

KUENTSCHER .. " " " "

" Zbl. Chir. 1941 857

" " " 1942 1837

" Orthop. Kongr. Wien 1944

LANGE .... Zschr. orthop. Chir. Bd. 47 S. 519 (1926)

MAATZ .... Arch. orthop. u. Unfallchir. Bd XLII S.513 1943

" ..... orthop. Kongr. Wien 1944

N " .....orthop. Kongr. Dresden 1943

NORDMANN ... Chir. Kongr. Berlin 1940

ORELL, S. ... Zbl. Chir. 1941, 1398

SWANTE ANNERSTEN ... Arch. Klin. Chir. 204 Bd. S.299 (1943)

TROJA ... De novorum osseum regeneratione Paris 1775

J.VERNE, G.M. MENEGAUX, J.M. VERNE, and J. B. MAGNANT
.... Press. méd. 1941, 452

Reprint from the
ZENTRALBLATT FUER CHIRURGIE

70. Jahrgang, Nr. 11 - 1943

Verlag von Johann Ambrosius Barth in Leipzig

From the Surgical Clinic, University of Kiel

Director: Prof. Dr. A. W. FISCHER

THE SIGNIFICANCE OF FAT EMBOLISM IN THE MARROW NAILING METHOD OF KUENTSCHER

by
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Translation prepared by:
U. S. Naval Technical Unit, Europe, (Medical Section)
Office of Naval Advisor
Office of Military Government (U. S.)

Experience has shown that fat embolism is not a hazard to be feared in the marrow nailing method of KUENTSCHER. In spite of this experience I have re-examined this question by some animal experiments. From our combined experience with the marrow nailing (A. W. FISCHER and MAATZ) we had to admit that in some border-line cases it could not be determined if dislodged fat had played a part in the fatal end and if the marrow nailing method was the decisive factor. Hundreds of marrow nailing operations have proven that in the case of a single fracture of a limb with a generally good constitution of the patient, fat embolism does not occur in sufficient extent to give clinical symptoms. On the other hand, it is important to know how extensive a fat embolism follows marrow nailing so that it may be considered in the judgement of cases where the general constitution has been materially effected (as for instance by multiple fractures or extensive injuries) and an additional hazard is not added in a case of doubtful outcome.

In 19 fatal cases including those treated with the Y-shaped nail of KUENTSCHER, 6 could not be autopsied. Judged by the clinical picture one of these fatalities might well have been determined by a fat embolism:

The patient was the 44 year old A. M. On May 4, 1940, she fell out of the first floor and suffered, in addition to fractures of the neck of the femur, of the lower jaw, and the bridge of the nose, a further fracture in the middle of the shaft of the left femur. On May 8, four days after the accident, a nailing of the fracture of the femur was made with the patient in a generally good constitutional state. The operation was done without difficulty. On the evening of the same day the general constitution began to grow considerably worse and at 2.00 a.m. the patient died with the symptoms of an embolism showing pale cyanosis and dyspnea. The patient was very adipose. The husband refused to give permission for an autopsy.

Four out of thirteen autopsied cases showed a more or less extensive dislodgement of drops of fat into the very fine vessels of the lung:

Patient M. L. 64 years old. We had to deal with pertrochanteric fracture on the left side with marked displacement. During the nailing which was performed the day following the accident, a very great hematoma of the fracture drained off. In other respects the marrow nailing operation was not unusual. Postoperatively a severe circulatory collapse occurred. The patient died the same day without recovering from the collapse. The important pathologic-anatomical findings were: flabby brown heart muscle, an early bronchitis with small bronchopneumonitic foci and a moderate sized fat embolism in each lung.

Patient E. T., 78 years old. In this case we had to deal with a very weak patient, with a pertrochanteric fracture on the right side. On the third day after the accident the marrow nailing was done without complications. After this, however, the general constitution of the patient grew steadily weaker and 5 days after the operation he died. The autopsy showed the following findings: slightly sclerotic,

flabby brown heart muscle, arteriosclerotic shrunken kidneys, a discharging parotitis with an infiltration of discharge into the mucous membrane of the larynx and of the throat, chronic congestion of the liver with a peripheral fatty degeneration, a chronic endometritis, and a small fat embolism.

Patient F. L. 42 years old, was sent to the clinic on May 17, 1941 with a transverse fracture in the middle of the right femur. In addition the patient had suffered a fracture of the lower jaw, a lensshaped hematoma and a concussion of the brain. The nailing operation was made on May 24, 1941, without any complications. The day after the patient died because of a failure of the circulation. The autopsy showed the following finding: Trivial skin injuries, extensive hemorrhage of the soft parts, especially in the lower limbs, a surgically treated fracture of the shaft of the right femur and a heavily discharging bronchitis as well as areas of consolidation in both lower lobes. The microscopical examination indicated a moderate amount of fat in the fine vessels of the lung.

Patient M. P., 20 years old, was sent to the clinic on August 24, 1941, with a fracture of both legs. The patient was suffering from a severe shock, but in other respects she was in a very good general condition. On August 24, a nailing of both legs was made after the patient had recovered from shock. From the shock which arose after the nailing operation the patient did not recover and she died on August 28. The findings of the autopsy were: Extensive fat embolism in both lungs with a heamorrhagic-inflammatory infiltration of all lobes of the lungs.

Especially in the last mentioned case one would think that the postoperative fat embolism might have played an important part in the fatal outcome. The findings of the other patients differed so considerably that it might well be concluded that the embolic dislodgement of fat was not decisive.

Whereever the new method of marrow nailing according to KUENTSCHER began to be known, fat embolism was feared in addition to other considerations. It is obvious that numerous arteries and veins are opened by driving a big foreign body into the bone marrow. The severed arteries containing blood, constantly under pressure, create a hematoma. On the other hand, the veins, gaping open as they do, drain off the blood and along with it drops of fat, perhaps even by suction.

Let us now discuss briefly the mechanism of fat embolism as demonstrated by research.

The two possibilities for the development of fat embolism can be explained on either mechanical or a colloid chemical basis. The latter one is of no interest with regard to the marrow nailing. It is caused by a flowing together of the very fine emulsion of fat circulating in the blood. LEHMANN and MOORE noted this occurrance after Histamin injections. REICHER, v. SEEHEIM, LEHMANN and MOORE and FAZEKA during ether anaesthesia, while ZSCHAU observed

it in the case of aseptic decay of tissue.

While v. WILLMS and FRITZSCHE regarded the mechanical dislodgement of fat through the veins as improbable, there is, according to the research of all the other authors, hardly any doubt, that this crude, mechanical dislodgement is the usual method of formation of fat emboli. According to BUSCH later BLOURNY, v. BERGMANN, PELLIS and others the vessels are torn in the case of a fracture. An increased pressure is created in the marrow space and the blood carries drops of fat out through the veins. Thus the fat comes first into the respiratory circuit and later into the general systemic circuit of the blood vessel system. The entrance of the fat into the veins is facilitated by the gaping rents in the veins as proven by LANGER. It is not clear whether or not a suction effect of the veins plays any part (BUSCH). According to HOFHEINZ this does not seem very likely as the veins are too far distant from the heart. The examinations of LARSEN are of interest in this matter, for he has proven physiologically that an increased pressure exists in the marrow space. This fact is the probable explanation of how trivial injury, even a bumping of the shin bone, might cause a fat embolism (RIBBERT).

KUENTSCHER points out that the development of fat embolism in the case of marrow nailing does not seem very likely, as the nail does not fill up the marrow space like the piston in a syringe, and therefore the possibility of an increased pressure in the marrow space in front of the nail does not exist. The V-shaped cross section of the nail fills the marrow cavity only partly and it leaves sufficient space for the drainage of the blood, which can drain off between the nail and the guide rod at the place of introduction. This is true even in the case of a percutaneous marrow nailing, for practical experience has shown that sufficient room remains for drainage. As long as the blood containing fat, can run off easily, the possibility of a fat embolism hardly exists at all. It was also observed by HOFHEINZ that fat embolisms occur very seldom in cases of open fractures.

Undoubtedly KUENTSCHER's considerations are valid. On the other hand it cannot be denied that a fat embolism may be possible in spite of the above mentioned favorable factors, for the smoother the operation goes, as for instance in the case of a percutaneous femur nailing, the smaller will be the possibility for drainage at the place of introduction. As soon as the guide has been removed after finishing the operation the conditions are again favorable because of the wide opening at the head end of the nail. According to theoretical considerations alone, however, a drainage of fat through the veins caused by an increased pressure in the marrow space might occur in the meantime. An insignificant dislodgement of fat is of no clinical importance. All clinical methods or its detection are inadequate. According to MAGNUS and JACOBI capillary miscroscopy indicates numerous failures at the place of the fold of the nail. KILIAN, KLAPP, STRUPPLER and others found negative results on the retina of the eye, even in cases of a fatal outcome, in contrast to the findings of OPPOLZER and URBANECK. In cases without clinical significance the

determination of fat in the blood is not indicated, (v. NATHER and SUSANI, FLICK and TRAUN), RAPPERT regards this to be of importance only as a forecast of prognosis in severe cases. Excretions of fat in the urine could be observed only in extremely rare cases.

Desisting from all questionable examinations on patients I regarded it as indicated to find out by animal experiments if any fat embolism occurs at all, and if so, to what extent.

In the first experiment nails were driven into both tibias and both femurs, all being sound bones, of a middle sized dog under Somnifen-anaesthesia. This duplicates the technique of femur nailings on human beings, for in case of nailing the shin-bone of a dog a straight nail can be introduced into the marrow cavity from the wide tuberositas tibiae. The dog was killed after 30 minutes by opening the thorax.

As might be expected no sign of dislodgement of fat could be discovered in the dog while still anaesthesized. The lungs, kidneys and the brain were examined histologically. The section of the kidneys and of the brain were imbedded in celloidin and dyed with sudan. These showed small drops of fat lying in the capillaries. One can rightly take it for granted that in general the fat is at first stopped in the capillaries of the lungs. On the other hand, the experiments of REUTHER and NAKATA have demonstrated that fat injected into animals might within a few minutes be divided between the respiratory circuit as well as the general systemic circuit of the blood vessels system. SKIBAS has observed the first drops of fat in the capillaries of the spread out tongue of the frog within 42 seconds after a fracture of both legs. Therefore the fat must have passed through the lungs within this time.

Small drops of fat, having some slight variations of size, were uniformly distributed throughout the lungs. A preference of the lower lobes could be clearly recognized according to the findings of KRETZ, which findings were not accepted without question. In a sectional area of 4 square millimeters two or three drops of fat could be seen in the capillaries. We are therefore dealing with an extremely slight degree of fat dislodgement into the lungs. Only at some isolated places in the right lower lobe 10 to 20 drops of fat could be seen in the area (4 square millimeters) of which some were of larger size.

In the second experiment both the shin-bones of two guinea-pigs were nailed under ether anaesthesia and with the same technique as in the case of the dog. The first animal was killed after 12 hours, the second after 24 hours. Only after a long search could some drops of fat be found, which were widely separated in the capillaries of the lungs of the first animal. The findings of the other organs did not indicate any disease. In the case of the second animal no signs of fat could be recognized in any organ.

The findings obtained indicate that fat embolism may occur in the marrow nailing method of KUENTSCHER. The incidence, however, is so insignificant, even when four long bones are nailed at a time, that it is of no practical importance. In this case there is a disagreement between my experiences and the clinical experience, as already mentioned in the beginning.

When treating patients whose clinical picture caused by the injury indicates that a fat embolism has to be feared we should not nail. This is to avoid any slight additional tendency to fat embolism. In the above mentioned considerations it should be especially pointed out that aside from the peculiarity of the operation (the insertion of the nail into the marrow) which necessarily leads to severe shock of the effected part, even the manipulation of the injured limb considerably increases the danger of a fat embolism.

S U M M A R Y

It has been proved by animal experiments that a dislodgement of fat into the lungs might take place in the marrow nailing method of KUENTSCHER. The incidence of fat embolism in these cases is so infrequent that it is not a complication of clinical importance. Because of our clinical experiences we must emphasize that patients should not be nailed if an embolism is for other reasons to be feared, not only because of the usual important indications but also because of the possibility of an increased likelihood of dislodgement of fat.

B I B L I O G R A P H Y :

(1)	BERGEMANN	Berl. Klin. Wschr. 1910 #24
(2)	BERNHARD	Muenchn. med. Wschr. 1925, 1590
(3)	BUSCH	Virschows Arch. 35, 321
(4)	FAZEKAS	Zitat nach Struppler
(5)	FISCHER-MAATZ	Arch. klin. Chir.
(6)	FLOURNOY	These Strassburg 1878
(7)	FRITZSCHE	Dtsch. Zbl. Chir. 107, 1910
(8)	HOFHEINZ	Neue dtsch. Chir. 55
(9)	KILIAN	Dtsch. Zbl. Chir 231, 97 (1931)
(10)	KLAPP	Zbl. Chir. 1931, 2594
(11)	KRETZ	Beitr. path. Anat. 1912, 55
(12)	KUENTSCHER	Chir. 14, 161, (1942)
(13)	LARSEN	Zit. bei Struppler
(14)	NAKATA	Rev. med. Suisse rom. 1918, 38
(15)	OPPOLZER	Verh. dtsch. Ges. Chir.57,Kongr.1933
(16)	OPPOLZER and URBANEK	Wien med. Wschr. 1931
(17)	REICHER	Zbl. klin. med. 1908, 65
(18)	RIBBERT	Dtsch. med. Wschr. 1900 Nr. 26
(19)	W. REUTHER	Frankfurt. Zbl. Path. 1915, 17
(20)	v. SEEMANN	Dtsch. Zbl. Chir. 1931, 230
(21)	SKRIBA	Dtsch. Zbl. Chir. 12, 1880
(22)	STRUPPLER	24. Tag. bayr.Chir.Ver.Zbl.Chir 1940 265
(23)	v. WILMS	Sem. med.(Fr.) 1910 zit. bei Hofheinz
(24)	ZSCHAU	zit. bei Struppler

No. 4

BRUHN's Contributions to Clinical Surgery

Reprint from volume 174, 1943

Published by Urban and Schwarzenberg, Berlin and Vienna

From the Surgical Clinic of the University of Kiel

Director: Prof. Dr. A . W. FISCHER

CONCERNING THE COURSE OF BONE INFECTION AND REGENERATION FOLLOWING MARROW NAILING OF SIMPLE AND COMPOUND FRACTURES AND OSTEOTOMIES

by

Doz. Dr. Richard MAATZ and Dr. Horst REICH

Assistants at the Clinic

With 7 Illustrations*

*(The microscopical pictures, Ill. 4, 5,6, could not be reproduced because the negatives were no longer available. An attempt has been made to trace the X-ray pictures, Ill. 1,2, 3,7, on the stencils for this article).

Translation prepared by:
U. S. Naval Technical Unit, Europe, (Medical Section)
Office of Naval Advisor
Office of Military Government (U. S.)

At the Surgical Congress in Berlin in 1940, NORDMANN and KOENIG expressed serious misgivings that the marrow nailing according to KUENTSCHER might set back the operative treatment of bone fractures into an earlier period. In contrast to this, A. W. FISCHER pointed out, that in this case it is not a question of an operative treatment of fractures in the usual sense of previous times as the fracture is nailed from a distant place without exposure of the fracture site. Consideration of this method justifies the point of view that the danger of infection, which is feared in the surgical treatment of fractures, plays a minor and unimportant role.

The operative wound on the thigh for the marrow nailing is only long enough to permit the nail to be inserted through the skin. On the ulna and the radius it corresponds to a stab incision, on the arm above the elbow and on the leg it is only slightly larger. These small wounds in the soft parts must be considered as only slightly liable to the danger of an infection.

Practical experience has proved this to be true. In more than 200 cases of marrow nailing we have observed an infection of the place of insertion of the nail only 7 times. In a work of A. W. FISCHER-RÜCH recently published in the Zentralblatt fuer Chirurgie, 6 observations concerning this subject were mentioned. To these one new case has been added here.

A mild, locally limited inflammation arose, which healed after a short time. No infection of the marrow cavity following the marrow nailing of a simple fracture of the shaft arose in any case where the nailing was made immediately after the accident. Some exceptions will have to be discussed later. In this connection we wish to point out that we had to deal with some unusual cases. They are included in the above mentioned 7 cases.

Compared with other aseptic operations (as for instance inguinal herma with an incidence of 2,3% according to TEICHERT, 6,8% according to GROGON and 5% according to KIRSCHNER) this number of infections may properly be called low. It is of no practical importance, as an infection at the place of insertion of the marrow nail is not of equal significance to an infection at the place of fracture, for the distance from this operational wound to the place of fracture is usually considerable.

In discussing this question, it should be pointed out that the metal nail has an oligodynamic effect and that it guarantees an exact fixation and maintenance of quiet of the fragments which are generally accepted as desirable circumstances in fighting inflammation. Finally we wish to emphasize in this context the fact that, according to the examinations of LEXER, LOOSER, W. MUELLER, ERB and BORDASCH, bone marrow shows only a slight tendency to inflammation and that it has obvious resisting ability at its disposal.

This is also confirmed by the observations of a successful course of healing of a few marrow nailing operations, in which, in spite of an infection of the insertion canal, no infection of the marrow cavity and, therefore

no suppuration at the place of the fracture arose.

To a certain degree, the circumstances of the nailing of the neck of the femur may be compared to this operation. They are certainly more unfavorable, for the distance from the place of insertion of the nail to the fracture is considerably shorter than in the case of a marrow nailing. In 163 cases of a nailing of the neck of the femur (until 1939) we have only once observed an extension of the inflammation to the place of fracture (KUENTSCHER).

Our experience with 165 uncomplicated marrow nailings according to KUENTSCHER have confirmed our suppositions. These figures, however, refer solely to the uncomplicated nailings of simple fractures. No cases where the place of fracture was exposed, compound fractures, osteotomies or so-called Y-nailings are contained in them.

As we shall see later on, the exceptions mentioned above are to be regarded only as such. They do not prove the theory incorrect that practically no danger of an infection during the marrow nailing is to be expected. It should, however, be observed, that here we mean merely the nailing as first mentioned by KUENTSCHER, namely the nailing of a simple fracture of the shaft without exposure of the fracture-site. If one therefore limits the use of this method to simple fractures and interrupts the nailing if an adequate closed fixation does not seem to be possible, one might rightly say that the patient was not exposed to the danger of an infection of any importance by the operation. Nowadays these considerations certainly do play an important part, as we have to deal with a new procedure which is meant to supersede approved old methods.

After his first successful nailings, KUENTSCHER extended the indications. By animal experiments, the results of which were not published because of the circumstances of the war, KUENTSCHER could demonstrate that a compound fracture will also heal excellently after the nailing. Finally the use of the marrow nail has proved to be especially successful in cases of osteotomies.

The circumstances with regard to the danger of an infection are entirely different in cases of osteotomies and are still less favorable in cases of compound fractures. The fracture site is exposed and the germs can easily find access. In cases of compound fractures it is even to be expected that wounds in the soft parts and in the bones are all more or less infected. Therefore, infections were to be expected and they have arisen.

It will be of special importance to find out what course an infection takes after the marrow nailing. Has the nail a decisive influence on the course of the inflammation of the bone? Has this foreign body, which runs through the entire marrow canal, any disadvantageous influence , or does the fixation of the fracture parts (by which they are kept in a quiet and resting position) by the marrow nail offer a considerable advantage?

One will in any case have to expect some infections in cases of osteotomies and compound fractures. It should depend on the mild or the virulent course of the infection, whether this procedure will also be successful in these conditions. It could not be decided from the very beginning, whether or not this extension of the indications would be an advantage for the marrow nailing method. The only thing that could be done was to find this out slowly by experiments. It was only recently that we learned that RAISCH (Wiener med. Ges., July 2, 1942) has observed progressive marrow phlegmons with a sepsis and a fatal issue after the marrow nailing of compound fractures during experiments on guinea-pigs. This might cause a certain anxiety.

The hospital reports of the clinic at Kiel which have been collected since the introduction of the marrow nailing method, are sufficient to form a temporary judgement and to give general directions for further practical methods of treatment.

Are all compound fractures to be nailed or are part of them to be excluded and according to which points of view are the hospital reports to be selected? Are the obviously great advantages of the marrow nail, as for instance in case of an osteotomy of the thigh, offset by the fact that an infection is to be feared? Is the course of this infection of such a character that one might conclude that an increased danger for the patient arises because of the marrow nail?

Recently A. W. FISCHER and MAITZ reported in detail the hospital reports of the patients of the Clinic at Kiel. Including the cases of observations, kindly placed at our disposal by other hospitals we now have at our disposal 14 cases of observed bone suppuration following the marrow nailing according to KUENTSCHER.

Because of the great importance of the question it seemed indicated to collect these cases and to submit them to a critical examination. In this dissertation those observations are also contained, concerning which A. W. FISCHER and REICH discussed the question of osteomyelitis in case of a marrow nailing of compound fractures.

Purposely only cases of infection are to be discussed in this work, for it is only from such cases that we can derive the experiences required for our future decisions in practice. As emphasized before, these observations were made during the tests of a new method of treatment.

As regards the 14 cases of a suppuration of bone following the marrow nailing they have to be classified as follows:

Following the typical KUENTSCHER marrow nailing (simple fracture of the shaft)	3 times
Exposure of the place of the fracture	2 times
Compound fractures	5 times
Osteotomy	4 times
	14 times

As to the cause of the above mentioned bone infections the following 3 observations are of special interest:

1. Walter M., 18 years old, was sent to the clinic with severe injuries on the 27 Feb 1942. Besides a compression fracture (XII.B.W.) with an angulation of 25°, the patient suffered an injury of the right knee-joint, extensive hematoma in the soft parts of the trunk and on both thighs as well as a simple transverse fracture of the left leg in the middle of the shaft. Immediately a careful debridement of the wound of the knee-joint was made and it was sutured in layers. On the following day the vertebra was successfully fixed according to BOEHLER. When on March 4, the impression was gained that the wound of the knee-joint would heal primarily, there was no hesitancy about performing a marrow nailing of the leg. This was accomplished easily under Evipan narcosis. No additional fixation was required. Two days later an increasing anemia (Hb. 37% at 1,6 mill. erythrocytes) accompanied by an increase of the pulse rate without a rise of the temperature was treated with a blood transfusion. On March 7, the corset-like plaster cast was split in the shape of a basin because of difficulties in breathing. On March 7, septic temperatures arose. At the same time an infectious exudate drained off from the knee-joint. The wound was opened. On March 14, the hematoma, including the one at the fracture of the leg spread painfully. Incisions demonstrated that these collections of blood were full of pus. A thick brown pus drained off. In all cultures haemolytic streptococci were found. The temeprature remained septic, a plaster cast around the pelvis was put on and several blood transfusions were given. The suppuration in the knee-joint extended to the thigh and to the leg. On April 22, the right thigh was amputated. In the same evening the patient died.

This case showed an <u>infection of a fracture hematoma</u> of a simple, nailed fracture of the leg with a <u>pyemia</u>, which was caused by an infection of the knee-joint of the other side. As the patient died early, the course of the suppuration at the place of the fracture could not be observed. It should be mentioned that in addition the hematomas of the thigh were infected by metastasis in the same way and at the same time.

The occurrence of infection in the following two cases is also exceptional:

2. In this case we had to deal with a 2 year old child, Karla B., who was sent to the clinic with a transverse fracture of the right femur at the level of the middle of the shaft. As the fracture remained turned sideways and

shortened in spite of a suspension bandage with adhesive plaster by the traction method and in spite of several attempts to set it, marrow nailing was performed on the 7th day of treatment (August 1, 1941). This was a very difficult operation. It was from this case that we learned that a sharp guide rod is very unsuitable, exspecially in the case of small children. Again and again the guide rod attempted to penetrate the corticalis in different places. Aft r considerable trouble the introduction was accomplished. Then the marrow nail stuck fast in the marrow cavity which was obviously a little too narrow for the nail and it could not be inserted as deep as desired. It was protruding from the head of the femur almost 4 centimeters a distance too great in cases of small children. As the operation had required too much time already, one desisted from changing the nail once more.

During the first week no complications arose in the course of the treatment. After 3 weeks a small fistula developed at the place of insertion of the nail. At the bottom of this fistula the nail could be felt. As the X-ray showed sufficient callus formation and one could also expect sufficient consolidation of the fracture because of the youth of the patient, the nail was removed 5 weeks after the nailing to allow the fistula to heal in this way. A few days later the child was released at the urgent request of the parents. (8 Sep 1941).

On 24 September, 2 weeks later, the child was again sent to the clinic. The temperature rose to 38,5° C. In the area surrounding the place of the fracture of the thigh a fluctuant swelling was detected. The X-ray did not give any indication of a sequestrum. An intensive growth of callus at the place of fracture could be clearly recognized. The ends of the fragments showed a slight reduction of calcium as compared with the usual proportion of calcium of the bone. An incision was made, considerable quantities of pus drained off, and the rough bone could be felt. A hip spica cast with window was applied. After that the infection in the old fracture site subsided to some degree. On 22 November a second incision of an abscess was made. On December 20, the child was released and all the wounds were healed.

The question now arises: Which facts account for the development of the suppuration in the fracture site? Undoubtedly the laborious operation and an unsuitable marrow nail caused injuries to the marrow and the corticalis, such as will not regularly arise in cases of marrow nailing. The fact that the marrow nail was protruding too far and thus irritated the surrounding tissue, first led to a locally

limited infection combined in this case with considerable contusion of tissue at the place of insertion. This soon resulted in a fistula suppuration which disappeared after the removal of the nail.
Some weeks later an abscesslike suppuration appeared at the fracture site, which obviously had developed downwards along the marrow canal and which settled at the place of the least resistance of the tissue. As we shall see later on, the bed of the marrow nail is separated from the rest of the marrow by granulation tissue within a short time. The granulation tissue forms a kind of mantle around the marrow canal and thus prevents an extension of the infection to all the parts of the marrow (marrow phlegmon) as well as to the compacta and the periosteum. In the canal itself, however, infectious matter may spread downwards and collect at the place of the greatest destruction, the site of the fracture and thus cause suppuration. We shall see later such cases where the nail is still inside. Under these circumstances the bed of the nail acts as a sort of drain, which allows the pus to drain off through the place of insertion and thus prevents a more extensive infection. In this case also the suppuration remained confined to the fracture site. During the entire process the callus formation was quite satisfactory. The bone showed a moderate clacium reduction only temporarily and even this could be observed only at the time of the suppuration. No sequestration occurred. Thus there remains merely the picture of a suppuration of the place of the fracture, which has obviously arisen in the marrow canal after a fistula suppuration at the place of insertion of the nail.

3. We had to attend Mrs. Luise E., 45 years old. She had an accident in the morning of August 9, 1942 and was sent to the clinic in the afternoon of the same day. The patient was suffering from a fracture of the left tibia resembling the mouth-piece of a flute near the upper end of its lower third combined with a severe hematoma. The marrow nailing was done on August 11, under Evipan narcosis. There were no difficulties. An X-ray examination indicated a perfect position of the fracture pieces. Because of the severe hematoma and as the nail did not fix the fracture pices quite firmly, the marrow cavity being very wide, the affected limb was treated by the VOLKMANN splint method. The temperature did not rise. The patient felt well. The place of insertion of the nail, however, discharged pus from the beginning. On August 21, the stitches were removed. A small fistula suppuration existed at the place of insertion of the nail, which did not improve even after some time. On September 16, the nail was removed during which procedure pus was discharged. Haemolytic streptococci were found in the cultures. The secretion decreased. On October 29, a severe swelling, reddening and fluctuation arose at the fracture site. An incision with a counter incision and drainage was made. Much pus was discharged. No rough bone was felt. An X-ray examination on November 10, yielded the following finding: Spotted gradual fading of the entire bone. No sequestration. The drains were removed. November 18: The temperature

rose to 39,5° C. Slowly increasing painful swelling of the left ankle. November 23rd: Incision. The joint was free.. Fluid pus drained off. A plaster cast with a window was applied.

Although the end of this cas cannot yet be foreseen, the picture of a pyemic condition can already be clearly recognized. The starting point is an infection at the place of insertion of the nail. In the course of this process a suppuration of the place of fracture has arisen without a sequestration following. So far the course of this case corresponds to the one mentioned above, Then followed a suppuration of the left ankle. The general condition is serious affected. This is the first observation of this kind during the marrow nailing of a simple fracture of the shaft.

It will be easier to explain the development of the suppuration in the following cases, as it concerned either the exposure of the place of a fresh fracture or of a compound fracture, or of osteotomies. Here it might be pointed out that exposures of fresh bone fractures became less frequent as more experience in this new procedure was gained. None were performed this year (1942).

We are now going to describe 2 cases of bone suppuration following an exposure of the place of fracture:

4. Herbert G., 20 years old. On 28 February 1940 he suffered a direct fracture of the right leg, slightly below the middle. A plaster cast according to the traction method was applied. As the fracture did not heal well, a marrow nailing with the flexible marrow nail according to KUENTSCHER was performed on 24 March 1940. During this operation the place of fracture had to be exposed, as the fixation did not succeed. It was one of the first cases of marrow nailings of the leg. On 8 April the stitches were removed. The wound discharged. The fever rose to 39° C. On 19 April the suppuration at the exposed place of fracture had increased. The wound was examined. A counter incision was made. On 29 April the suppuration decreased. Sufficient callus formation could be observed, (see Ill. 1). On May 7, the recurvation was fixed under anaesthesia and a plaster cast was applied. On May 26, this plaster cast was removed. On the same day the patient began with exercises. On July 7, a small sequestrum separated. A severe edema in the ankle was observed after the patient got up. On July 15, the nail was removed under Evipan anaesthesia. Clinically the fracture was firm. On July 20, a good healing process with sufficient callus formation could be observed. On September 21, the patient was discharged. The fracture has healed in proper alignment. A moderate bone edema still existed. The patient had a slight limp in his gait. At a later examination in August 1941, G. had no more trouble. All the wounds had healed. The X-ray showed excellent contours of the bone exactly like that after a fracture healed without suppuration.. No edema existed.

After careful consideration it must be pointed out here that a direct fracture of the leg was nailed with exposure of the place of fracture during a delayed healing process. This was one of the first nailings of legs, in which the so-called flexible rigid nail was used. A lengthy suppuration of the place of fracture with the separation of a small sequestrum occurred. An exposure of the wound as well as a counter incision were required. The general condition of the patient was at no time really effected. Even during the suppuration sufficient callus was formed. The callus formation also remained intense, probably stimulated by the metal of the nail. After 4 months, the nail was removed and the fracture had healed firmly. A final examination after 1 year showed that the contours of the bone were clearly visible even at the place of the former fracture, and the leg was again fully restored.

5. W. K., a 7 year old boy. Hospital report No. 3436/41. He was sent to the clinic on March 20, 1941 with a simple transverse fracture in the middle of the right thigh. On March 24, a marrow nailing with exposure of the place of fracture was performed, as a non-operative fixation did not succeed on account of obstructive muscles. In consequence of this a burn of the third degree was caused on the left thigh by the X-ray bulb. The rising temperatures setting in afterwards were due to an inflammation caused by the burn. On April 9, the patient was removed to the Heilanstalt (Mental hospital) Schleswig. (it was a case of mongolian idiocy). On May 9, the patient was brought back to the clinic as a larger abscess had formed on the inside of the right thigh. A wide incision was made. The abscess was exposed completely. On May 31, another incision was made. After the temperature had risen several times the suppuration subsided again. Hemolytic streptococci were found. A hip spica cast with a window was applied. Afterwards a suppuration draining from two fistulae arose, one located on the outer side and the other on the inner side of the right thigh. In the X-ray of September 23, a ring-shaped sequestrum could be recognized in the area of the osteotomy, which sequestrum was about the size of a chestnut. The adjoining bone parts were atrophic. Around the sequestrum a large necrotic area (involucrum) was observed. On November 7, a sequestrotomy was performed and the nail was removed. A cylindrical sequestrum was removed without difficulty. A corresponding large cavity remained. On November 14, the patient was examined once more. With the exception of small fistulae the wounds had closed on March 9. On March 15, the patient got up and on April 11, he was discharged with only a very small suppuration fistula on the side of the thigh.

In the above mentioned case the infection of the exposed fracture site caused an osteomyelitic picture. A ring-shaped sequestrum formed. We shall enter into particulars about this later. Furthermore a strong periosteal formation of new bone involucrum could be observed. The suppu -

ration remained restricted to the place of fracture.

We are now going to describe the course of bone suppuration in 5 cases of opened fracture:

6. Willi L., 39 years old. The patient suffered a transverse compound fracture of the right arm above the elbow. There was a 15 centimeters long, deep wound in the soft parts of the inside of the upper arm, which was gaping open and was only a little dirty. The bone which did not protrude, was however, visible in the depth of the wound. In addition to this the patient was suffering from a concussion of the brain and the left ear was almost completely torn off. The wound was immediately treat d and a marrow nailing was performed. An abduction plaster cast was applied (on May 30, 1941). On June 11, the wound had healed. The stitches were removed. On June 15, the plaster cast was taken off. On the same day the patient started with exercises. On June 17, he was feverish, temperature rose to 40° C. On June 18, the wound was opened again. A moderate quantity of pus drained off. On July 10, an incision was made again on the outside. On July 14, a new strong abduction plaster cast was applied. The fracture was firm. Immediately the temparature, which had been low febrile in character during the last fortnight, sank to normal and remained stationary. On August 15, the wounds had closed. The plaster cast was taken off. The patient took his exercises. On September 4, the patient was discharged at his own request with a firmly healed fracture. He was, however, unable to move his left shoulder joint freely.

While the wound of the bone healed firmly in due time, the development of the infection demanded a renewed treat-

Illustr. 1
Fracture of the leg, 5 weeks after nailing with exposure of fracture site. Formation of callus.

Illustr. 2
Open fracture of the leg near the foot-joint. Strong formation of callus. X-ray 4 months after the accident.

ment of the arm with a splint. A spreading of the inflammation to the bone could be recognized by the strong spotted calcium resorption with a sclerosis of the adjacent parts. No sequestrum had formed. The nail was not removed as the patient did not come back again.

The following case is particularly instructive as to the importance of the moment of the nailing.

7. B., 37 years old. On May 13, 1942 the patient suffered a transverse compound fracture of the leg with a wound 3 centimeters in length, which was not very dirty. The place of the fracture was at a distance of 4 fingers width above the ankle. The wound was covered with boracic ointment compresses and a moist bandage was put around the leg and a splint applied.

On May 22, a wire extension was made under Evipan-ether-anaesthesia. The wound discharged a little secretion. The temperature was normal. The swelling of the leg had decreased considerably. On May 28, the nailing according to KUENTSCHER was made under Evipan anaesthesia. On May 29, the temperature rose to 39,2° C. The patient had severe pains in the leg. On May 31, he had a septic fever. He was apathetic. On June 2, the temperature was still septic. The patient suffered from jaundice, he showed motorial unrest and extreme apathy. On June 4, some thin greenish yellow pus drained out of the wound. The patient was given large doses of Globucid (a sulfonamide) for 5 days. On June 9, an incision to the right and left of the operation incision was made. Drainage of all wounds was obtained. Apathy developed further. On June 13, the patient suffered from abscesses due to pressure over the coccyx and on the left heel. Wide incisions were made in the middle of the leg. The patient showed no interest whatever. A blood transufsion was given (350 cubic centimeter). On June 19, a blood transfusion of 400 cubic centimeter and on June 22, another transfusion of 350 cubic centimeter were made. 2 Tablets of Globucid were given three times. On July 3, the general condition had improved. The temperature amounted to about 38° C. in the evening. Curdy pus secretion drained out of all wounds. The leg was severely swollen. The skin was bluish-red. The abscesses due to pressure were as big as the palm of a hand. On July 24, necrotic pieces of tissue peeled off. On July 28, a blood count was made, the result of which was: 10 800 leucocythes, 2,2 millions erythrocythes, 43% haemoglobin. The temperature was temporarily normal, afterwards it rose again to 38° C. On August 17, the general condition had improved. All the wounds were clean and had decreased in size. On the leg curdy pus secretion still drained off. On September 10, the general conditions were acceptable. The abscesses due to pressure had almost

healed. The swelling of the leg had gone. All the wounds had healed except the two small ones on the outside of the thigh, out of which pus still drained. A new X-ray showed good position of the fracture and only slight antecurvation. A strong formation of callus could be seen bridging the fracture cleft in the femur. The fracture cleft is still recognizable. A slight, spottiness could be seen, especially on the inside of the shin-bone in the lower two thirds (see Ill. 2). On October 18, the nail was removed. The fracture was clinically firm. On October 22, the suppuration had clearly decreased after the removal of the nail.

This was a case of a compound fracture of the leg, which was nailed on the fifteenth day with a slightly secreting wound. Immediately a severely septic clinical picture developed, with jaundice, enduring apathy, large abscesses caused by pressure and abundant suppurations on the leg, which required several incisions. The clinical picture improved slowly. After 5 months the abscesses caused by pressure were healing. All the wounds on the leg were closed with the exception of two small ones, which were secreting moderately. The swelling of the leg had decreased considerably and the wound in the bone was clinically firm with a good callus formation (Ill. 2). The nail was therefore removed after 5 months. After the removal of the nail the secretion of pus decreased.

The following case shows a considerably delayed callus formation:

8. St., 64 years old. He had a compound comminuted fracture of the left lower leg, a transverse fracture slightly below the middle and a jagged comminuted fracture 5 centimeters below the tuberositas. The wound of the soft parts extends inwards and runs parallel to the shin-bone edge through the middle of the leg. It was 15 centimeters long. The bone was widely exposed.

The only possible immediate wound treatment was the use of approximation sutures. During the marrow nailing, which was performed under Evipan-anaesthesia with an additional ether narcosis the fixation gave considerable trouble, as the middle fragment had to be strung on the nail. Then the nail proved to be a bit to thick, it jammed in the middle fragment and carried this piece of bone with it, and distally it did not obtain sufficient firmness. The nail had therefore to be extracted. At that time we did not yet have the apparatus for removing the nails. During the attempt to extract the nail with a lifting jack, the front edge of the tibia was shattered. The nail was now struck out with an improvised hammer and a thinner nail was introduced. The thinner nail fixed the distal fracture well. The proximal fracture was not adequately fixed as the upper

end of the nail had an insufficient hold in the bone. A plaster cast was applied.

From the day after the operation, September 15, 1941, till September 18, several chills occurred. Then the temperature, which was at first septic sank to normal by lysis following intravenous Globucid (sulfonamide) injections. The swelling of the leg slowly subsided. On September 24, when the sutures were removed some turbid exudate drained off. Later on the wound, as well as the place where the nail had been introduced, discharged moderately.

On November 7, the plaster cast was changed. The leg was still swollen. A pronounced edema existed. On November 21, a loose bone splinter was removed from the wound. On December 29, the wounds showed no irritation and were clean. The place of introduction of the nail had healed. The nail was free for 2 centimeters at the junction between the middle and the upper third of the clean wound. On January 22, 1942, the nail was removed. The upper part of the nail was exposed by an incision for a distance of 10 centimeters. It was lifted with lever and driven out without any trouble. No reaction set in. During the following days the wound granulated well. One of the two fractures or both of them were still a bit elastic. A plaster cast with a window was applied. On March 14, a slight secretion of the wound was observed. The patient got up with the plaster cast. Three days later the plaster cast had to be cut open because of severe swelling of the leg. On April 5, the patient had a temperature of 40° C. The leg was severely swollen. A widespread erysipelas existed. During the following four weeks the inflammation did not decrease in spite of Globucid treatment. The general condition of the patient grew considerably worse. On April 13, a big subcutaneous abscess was drained. Afterwards the temperature fell and the swelling of the leg decreased. By June 11, the general condition of the patient had improved considerably. The fractures were still clearly moveable. The X-rays showed that on neither fracture had any considerable quantity of callus formed. The position of the distal fracture was satisfactory. The proximal fracture showed a bayonet-shaped dislodgement of the distal fragment in front and medially. The axial relation was satisfactory. The edges of the fracture were astonishingly smooth and without any callus formation (Ill. 3)

On October 2, the plaster cast was removed. The leg could bear weight without a plaster cast. All wounds were closed. Swellings of a moderate degree still existed.

This was a case of a severe compound comminuted fracture next to the tuberosity with a transverse fracture below the middle of the tibia. The wounds were dirty and could be treated only by approximation sutures. Owing to insufficient experience and bad luck the upper part of the nail had broken through. The clinical picture, which was at first strongly septic, soon stabilized. The nail, which was visible to an extent of 4 centimeters at the bottom of the wound, was removed after 10 weeks. After the patient had got up temporarily, the clinical picture grew worse because of a severe abscess like erysipelas, 5 months after the accident. The fractures 6 months after the accident were still elastic. The callus formation was much delayed. Although little callus could be seen then, 13 months later the clinical picture showed that the leg could bear weight again. For some time we believed that an amputation would be necessary.

9. W. J., a farmer, aged 60. Hospital report 2606/42. He was sent to the clinic on Jan 28, 1942, with a compound fracture of the bone of the right leg due to his having been run over. The accident had happened 24 hours before, it was a smooth transverse fracture of the bone of the right leg (including a fracture of the fibula), at the junction between the middle and the lower third. The treatment was rendered more difficult by an additional large dirty flesh wound, which seemed to be only superficial. In the lower third of the leg a large haematoma existed. Under Evipan narcosis the marrow nailing was performed without difficulties. Owing to the very wide marrow canal the nail did not fix the lower piece of the fracture quite firmly, a plaster cast with a window was applied. Later on the temperature was slightly irregular. Only once, however, did it rise to 39° C. The wound began to discharge and its surroundings began to swell. On February 7, it was unexpectedly found out that the soft parts, bruised when he was run over, had become necrotic down to the bone. The wound was now widely exposed to permit drainage for the beginning phlegmon. On February 28, the wound was again examined and a counter incision as well as drainage was made. On March 12, reddening and swelling of the place of insertion of the nail was observed, which had healed primarily before. After the incision a great deal of pus drained off. During the following weeks the suppuration was intensive at this place. It was, however, not so marked at the place of fracture.

On April 15, the nail was removed, as it was taken for granted that the nail was the cause of the suppuration. The suppuration decreased but it did not stop altogether. It was sustained by necrotic ligament tissue on the tuberosity until the necrotic tissues were excised. The ends of the fracture could still be moved freely.

Illustr. 3
Severe double fracture of the leg after removal of the nail. Delayed formation of callus. X-ray taken 9 months after the accident.

On April 23, the patient's leg was treated by the traction method with an extension wire through the heel bone, to prevent a shortening of the leg.

In an X-ray of May 7, no callus formation could be demonstrated. Instead of this a ring-shaped sequestrum could be seen at both ends of the fracture. Sequestrotomy. The dead bone rings had not yet become detached from the sound bone, so that they had to be removed by means of LUER's rongeur. On May 21, the leg was amputated 12 centimeters below the knee at the urgent wish of the patient, who wanted to be able to walk again soon and to look after his farm. The wounds remained open. Healing per secundam. The patient was discharged with a temporary prosthesis at the beginning of July.

Macroscopic finding of the bone preparation:

After the removal of all the soft parts, the bone of the leg does not show any striking features externally. With the exception of the above-mentioned place a layer of periosteum surrounds the shin-bone, it adheres closely to it, and does not show any changes or abscesses.

The place of fracture is merely covered by connective tissue. On cutting this tissue the scalpel grates, so obviously there must be areas containing calcium or some remnants of bone. By means of a saw the bone is now opened in its entire length. Thereby it can be observed that above as well as below the place of fracture the proportion of compacta and spongiosa have remained regular, as seen by the naked eye. In the section it can be clearly recognized that towards the inside an obviously compact connective tissue-like lining of the marrow cavity is present. Then follows marrow which above as well as below the place of fracture is rather soft and which obviously was infected at the place where the marrow nail lay. The circumstances described are exactly the same everywhere.

In the cross section a central formation of a hole, with a diameter of about 2 millimeters is present. It can be clearly recognized along the entire length of the marrow cavity. At the ends of the fragments next to the fracture the marrow is missing. Here intermediary connective tissue-like infiltration can be seen. It cannot be decided macroscopically to what extent it is a growth of new bone. It is astonishing that with the exception of the irregularities of the compacta caused by the fracture the compacta is in a completely normal condition as regards outward appearance. The area of the spongiosa around the ankle does not show any peculiarity. No sequestra are found anywhere. Everywhere very fine streaks can be recognized and no porosity or sequestration can be seen anywhere.

The condition of the soft parts, shall not be discussed in this work.

Examinations of the microscopic sections: They will first be made at the places of the fracture, later on other places will be examined, at a distance of about 10 centimeters above the place of fracture as well as cross sections.

Microscopical findings at the place of fracture: The portions of the bone marrow lying most central no longer show any marrow tissue in this case. Here we find principally a tissue permeated by foci, consisting mostly of small cells but containing also some of a polynuclear character. Besides masses of fibrin, numerous vessels with very delicate coats can be recognized in this tissue, which are partly distended and tightly filled with blood. This finding is made at those places which are situated next to the marrow nail. It is astonishing that only small concentrations of the inflamatory cells forming the focus of suppuration can be found here. This tissue, which cortaines many inflamatory foci, becomes a more and more typical granulation tissue, in which numerous histiocytes, which obviously store fat, can be found. This becomes more distinct the

nearer one comes to the marrow periphery.

This generally loose granulation tissue gradually changes into a more dense connective tissue

The microscopical picture Illustration #4 could not be reproduced because the negative was no longer available.

Illustration 4

Fracture site of an open fracture of the leg with a central inflammation of the marrow.

in which there are inflammatory foci principally as perivascular infiltrations of small cells. The vascular walls are thick. The inflammatory infiltration clearly decreases in quantity . Here we have the picture of a change of a centrally inflamed marrow section with a gradually more dense connective tissue capsule in the direction of the periphery. In this capsule there are also large hyalinized areas. In the areas next to the edge of this capsule the formation of fresh bone in the form of marrow callus can be recognized, extending rather evenly right up to the place of the fracture. The newly -formed bone spicules show a normal construction. It is a case of endosteal marrow callus and intermediary callus. Close to this new growth of bone there is the zone of the tibia compacta with a completely normal bone picture, in which no pathological changes can be recognized. Next to the place of fracture the HAVERSIAN-Canals are distended containing perivascular situated cells in addition to a fine meshed structure of fibrin and vessels. In the slightly distended HAVERSIAN-canals a more or less distinct bone formation can be observed.

Sharply separated from this compacta zone, a wide zone of closely applied periosteal bone is seen. Compact connective tissue appears at the outside. We have here a case of periosteal callus .

Microscopical finding distant from the place of fracture: Essentially the same picture was found here in the microscopic section with the exception of

The microscopical picture Illustration #5 could not be reproduced because the negative was no longer available.

Illustration 5

Formation of Callus in the peripheral marrow distant from the place of fracture.

the missing periosteal new bone formation as seen in the cross section. The above described pattern of tissue, however, was much more distinctly separated from the inside towards the outside. The most central areas of the marrow have changed to an inflammatory granulation tissue which is less firm towards the periphery of the marrow and becomes a compact connective tissue coat, within which the areas of inflammation decrease more and more. In this case too, an endosteal new formation of bone of the shape of well-formed bone spicules can be observed in the peripheral areas of this connective tissue coat. Then follows again the wide compacta zone and the periosteum. In neither of them could anything special be observed.

Summary. We found the picture of an inflammation of the central zone of the bone marrow, which was confined to the former bed of the marrow nail. In the peripheral marrow sections this inflammation was demarcated by the granulation tissue in such a way, that a compact connective tissue coat had developed. Only in the area of the place of fracture did the marrow still show marked inflammatory infiltration. Real abscesses could not be found anywhere. In no case did the picture of a marrow phlegmon with a complete decomposition of marrow appear. The compacta and the periosteum were not affected by the inflammation. Considerable new formation of bone in the form of closely applied periosteal bone in the area of the fracture could be observed, There is also evidence of bone resortion. Principally, however, we observed a new formation. Intermediary callus and marrow callus was formed. The latter was also formed at a distance from the fracture in the peripheral parts of the marrow.

10. R.F., a woman of 51 years. Hospital report Nr. 1608/41. The patient was sent to the clinic on September 30, 1941 with a compound supracondylar fracture of the right thigh. About 10 centimeters above the knee the proximal fragment of the femur was projecting for about 8 centimetors. On the front of the thigh the patient had a deep wound in the soft parts with a diameter of about 1½ inches. On both sides of the joint the outer layer of the skin was excoriated over a large area. The knee-joint was not visibly open. The extensor muscle was torn.

A debridement of the wound was made and approximation sutures were placed. Through and through drainage was provided for the big wound. The extensor muscle was sutured. The spicule of bone projecting from the proximal fragment of the fracture was removed. Then the fracture was fixed and a marrow nailing according to KUENTSCHER was made. This was done to prevent a dislocation of the distal fragment of the fracture. A plaster cast was applied.

On the following day the temperature had increased slightly. A hip spica cast with a window was applied. A fortnight later a more active suppuration and finally high temperatures rose. The general condition of the patient was seriously effected. Large doses of a sulfonamide (Globucid) temporarily brought the temperatures down to subfebrile ranges. In the meantime an X-ray examination on November 4, showed that the nail had penetrated right into the middle of the knee-joint separating teh two condyles along a very fine fissure extending into the joint, which had not been recognized before. After the temperature had risen again the wound was examined once more. The knee-joint was opened as it was full of pus. On December 2, the clinical picture of the patient was septic and the condition grew considerably worse. The thigh was amputated. On the following day the patient died. The result of the bacteriological finding was: haemolytic streptococci.

Illustration #6 could not be reproduced because the negative was no longer available.

Illustration 6
Open supracondylar fracture of the thigh with crown-sequestrum of the proximal end of the fragment.

The above photo (Ill.6) shows the preparation of the amputation. The condyles of the femur which were split apart can be recognized as well as the place of the transverse supracondylar fracture with a ring-secuestrum of the proximal end of the fragment which differs clearly from the rest of the bone by its white color.

The microscopic section of the following ar as was examined:

1. Parts of the form r place of the fracture with bone marrow and the bed of the nail.

2. Cross sections of the part of the femur above the fracture. After decalcification with Hemotoxylin Eosin the preparations were dyed with sudan according to van GIESON.

Fibrin was formed at the place of the former fracture as well as a narrow margin of non-specific inflammatory granulation tissue, which showed clearly against a background of close-and wide-meshed hyperemic marrow tissue containing perivascular infiltrati ns of small cells. The cells of the reticulum had a relatively large body of plasma and small vividly colored nuclei. Inside this reticulum there were obviously fat storing histiocytes. Then followed a zone of newly formed bone spicules with clear osteoblastic edges. In addition to the edema the marrow tissue showed a strong hyperemia and a relatively high number of diffuse small cell-like structures as well as histiocytes. The number of polynuclear cells was less.

In the cross section of the thigh above the place of fracture, a small strip could be recognized in the bed of the nail, composed of blood and masses of fibrin and intermixed with inflammatory cells. Here the design of the marrow had disappeared. Then followed a rather sharply defined non-specific inflammatory granulation tissue with increasing amounts of connective tissue towards the periphery. This inflammatory granulation tissue in turn changed into a loose granulation tissue. Finally close-and wide-meshed marrow tissue could be seen (fat islets) with more or less diffused perivascular small cell-like infiltrates, with minute hemorrhages and a surprisingly marked hyperemia. This was surrounded by the completely normal compacta zone and the periosteum without any sign of an ostitis or a periostitis. No progress of the inflammation through the HAVERSIAN-canals and no abscesses could be seen.

Summary of cases 9 and 10

The course of the clinical picture and the anatomical examinations have proven that it was an osteomyelitic condition, which had arisen as a result of compound fractures. The reason for the especially unfavorable outcome of the latter case of a compound supracondylar fracture of the femur was that a mass-infection of the knee-joint had arisen. Owing to a very fine fissure penetrating into the joint, which was not recognized in the X-ray, the nail had entered the joint and had thus caused a wide open connection between the infected place of fracture and the knee-joint.

In the other case we had a wide open fracture of the leg with a large wound of the soft parts, which could be treated only 24 hours after the injury. In both these cases the anatomical preparations are available. Thus we were able to examine the course of the inflammatory process in microscopic sections during a marrow nailing of compound fractures.

All the anatomical preparations show the same picture of a highly demarcated inflammation in the bone marrow. The picture observed here differs from the more or less characteristic course of an osteomyelitis in other respects as well. The inflammation is confined to the place of fracture and to the bed of the nail.

Also in these cases the development of ring or crown sequestrations can be observed in the area of the place of fracture. In the summary we shall give further particulars.

Four cases of osteotomies shall now be mentioned, in which bone infection developed.

11. Ernst W., 20 years old, It was a firmly healed fracture in a valgus position following an accident in 1936. On January 6, 1941, the patient had an osteotomy with marrow nailing. A moderate postoperative suppuration with a temperature of not higher than 38° C. developed. On February 6, the well cleaned gaping wounds could be treated with secondary sutures. A plaster cast with a window was applied. On March 28, the plaster cast was removed. The finding on X-ray examination was: no callus. The fracture was clinically firm. The patient started with walking exercises. Afterwards the infection increased. On April 12, another X-ray examination was made. The finding was: no callus. On June 26, a resection of the fibula was made. On August 8, the patient was discharged and had to come to the clinic only for ambulant treatment. Small fistulae showed on the wound of the osteotomy or at the place of the resection of the fibula. On October 9, the nail was removed under Evipan. On the following days an infiltrating suppuration of the glands in the left groin developed associated with fever. On November 22, the patient had to be discharged because of lack of discipline. The fistulae mentioned above were still there and were secreting slightly.

After this the patient could be examined no more. His office informed us that he had been called up for military service.

In this case all the wounds had become infected after an osteotomy of the leg and continued for a long period without affecting the general condition even temporarily. In spite of the fact that the X-ray did not show any callus when the patient was discharged 11 months after the operation, the wound of the osteotomy was clinically firm so that it could bear weight. 6 months later W. was in the service.

12. Max J., 25 years old. He was sent to the clinic on July 21, 1941 with a gunshot fracture of the right arm above the elbow. The wound healed after a prolonged suppuration. On January 26, 1942 the pseudarthrosis of the arm above the elbow, which had arisen in the meantime, was exposed. The ends of the bone were freshened. A LANE plate was put on. This plate was removed on February 24. On April 23, the ends of the bone were again freshened. They were united with two vertically lying wires which were introduced vertically into the marrow cavity. As the ends of the fracture were not firmly united by the growth of new bone, the wires were removed on August 21. A marrow nail was introduced into the marrow cavity from the proximal end of the bone. The marrow cavity distant to the body was opened with a crown gimlet and in this way the fracture was treated by an internal splint by the use of the marrow nail.

On the following days the patient had a temperature up to 40° C. The whole arm was swollen. Thin liquid pus drained off out of the operational wound near the fracture, for about 10 days. A fortnight later the temperature slowly decreased by lysis to normal. The swelling of the arm decreased too.

Today (October 10, 1942) all signs of an inflammation have completely disappeared. The fracture is still elastic.

This was a case of formation of a false joint of the right arm above the elbow after a gunshot fracture, about three inches above the elbow joint. This false joint had been operated several times before. The suppuration after the operation affected the general condition considerably; however, it remained locally limited. The formation of callus was poor. This is due to the fact that the ends of the fracture were not sufficiently freshened during the marrow nailing. We shall report about this in another place in connection with other similar cases.

The next patient showed a very good callus formation during the first few weeks. However, the strain on the regeneration power of the bone was very great as a considerable gap had to be bridged over between the pieces of the fracture. The callus formation stopped before this gap was bridged over.

13. S., Melanie, 20 years old. When a child, she had fallen on her right arm. Later on this arm was rather deformed. There was a limitation of movement in the elbow joint. On January 22, 1942, the patient had fallen again and suffered fracture of the stunted ulna. This fracture did not heal. The patient was sent to the clinic in this condition.

It was a case of a shortened very slender ulna with a pseudarthrosis about 2½ inches below the elbow joint. The radius had developed normally and was at least twice as thick as the ulna. The head

of the radius was dislocated and the radius was considerably longer than the ulna it was situated beside the elbow-joint.

On March 23, a resection of the proximal part of the radius was made. Then the distal part of the radius was united with the better developed proximal part of the ulna by the marrow nail. When the nail was driven in, a gap between the radius and the ulna of about 2 centimeters persisted, which could not be closed.

The next day the temperature rose to 39°C . The general condition of the patient was bad. At first the wound did not show any peculiarities. Afterwards an anemia up to 55% Haemoglobin and 2.8 millions red blood-corpuscles developed, while the temperature continued to be as high as 39° C. The wound which had been opened during the first few days discharged moderately. The temporary pronounced swelling of the area decreased slowly.

The general condition improved slowly as a result of a large dose of Globucid (sulfonamide) and of blood transfusions. The temperature, however, remained normal only after May 1.

On May 14, and even better on June 9, the X-rays showed a very good callus formation (Ill. 7)

Illustration 7

The cleft between the two fracture pieces was partly bridged over. Afterwards the formation of callus did not make any further progress. The place of fracture was still elastic. On October 20, the wounds were closed.

It was an infection combined with injurious effect on the general condition of the patient which had arisen after the proximal end of the stunted ulna had been united with the strongly developed radius. In spite of the infection the formation of callus was at first so considerable and uninterrupted that a cleft of 2 centimeters between the two pieces had largely been bridged over by callus as early as 8 weeks later. Later on,

however, the formation of callus stopped so that even today (October 20, 1942) there remains a cleft between the two bones, which moves slightly in spite of the nail.

14. Kurt K., 34 years old. At the age of 6 years the patient had fallen from the fourth floor into the street. Both femurs were broken. The right femur healed well, while the healing of the left femur was delayed considerably. The knee-joint could not be fully extended. When the patient was sent to the clinic at the beginning of March 1940, the left leg was 12 centimeters shorter. The femur was 7,5 centimeters shorter. In the X-ray it could be seen that the old fracture, about 4 inches above the knee-joint, had healed firmly while the fracture pieces had been pushed past one another and this had caused a considerable shortening. The knee-joint could not be extended beyond 130°.

On March 9, an osteotomy was performed. During this the back wall of the distal piece broke out to a large extent so that the nail could not find any proper grip. For this reason a steel band was put around the fracture. This operation was difficult and took a long time.

During the first few weeks the wound secreted little. Later on the secretion increased. On April 29, it had closed. The patient had no temperature. The plaster cast around the leg which had been applied after the operation was then replaced by a hip spica cast. On May 8 the wound opened again. The patient complained of severe pain in the left knee-joint. In the clinical picture no involvement of the joint by the inflammation could be demonstrated.

On September 9, the nail was removed, as it was considered possible that the severe pain in the leg and in the knee-joint might be due to the nail. During this process, little pus drained off at the place of introduction of the nail, the wound of which had healed per primum. The fracture had not yet healed firmly. In the X-ray it could be seen that the pice of bone which had broken out of the back wall was connected with its original bed by a large formation of bone. No callus formation could be seen at the place of the osteotomy. A ring-shaped sequestrum could be recognized between the pieces of the fracture.

On October 15, the leg was amputated at the place of fracture, as the general condition of the patient had grown considerably worse and the value of the leg with its restricted extension in the knee-joint had been reduced anyhow, and no callus formation could be observed at the place of fracture.

In this case an osteotomy was performed because of a shortening of the thigh caused by an old fracture. As the rear cortex had broken out, a firm support had to be obtained for the nail by ring-shaped steel band. The wound discharged. While the piece broken out was connected with its

original bed by a broad bridge of bone 3 months later, the place of fracture did not show any callus formation even 7 months later. A ring-shaped sequestrum had formed. As the value of the leg had been reduced anyhow by its delayed growth and the restricted extension of the knee-joint the general condition of the patient grew steadily worse, as he complained of severe pain and finally no kind of a callus formation could be recognized at the place of fracture, the leg was amputated at the level of the fracture after 7 months treatment. The wound healed slowly.

Recapitulation

We have described 14 cases of bone suppuration of various kinds and degrees, which arose in simple and compound fractures of the shaft as well as in osteotomies. In all these cases a marrow nailing was performed.

A biased observer might easily be inclined to attribute the development of infection in all these cases to the use of the big nail. Viewed under the clinical aspect, however, in all these cases the unfortunate course cannot by any means be regarded a surprising or remarkable in any way, at least with regard to the compound fractures, the exposed fractures and to the osteotomies. After all even a simple fracture may show a long delayed healing process with complications of different kinds.

Of course it is possible that an infection might arise even in cases of percutaneous marrow nailing of simple fractures owing to unfortunate circumstances. We have, however, mentioned in the beginning how seldom this happens. Only the three cases, which we have described in detail, show a serious development. In the first case a suppuration of the hematoma of the fracture with a pyemia arose, starting from a suppurative injury to the knee-joint on the other side. In the second case an infection developed at the place of introduction of the nail with a subsequent suppuration of the place of fracture after a difficult marrow nailing, which was performed late, on the seventh day of treatment. In the third case there arose a suppuration of the fracture and of the ankle with a general pyemia subsequent to a suppuration of a fistula at the place of introduction of the nail. From the technical point of view the operation itself was very simple in this case. In our hospital reports this observation has been the only one of its kind so far. It would certainly be a mistake to reject a new method of treatment, with which excellent experiences were made in other respects, on account of such rare observations. It should be pointed out in this place, too, that on the other hand many operative reductions can be avoided by marrow nailing.

In considering the different course of the disease in these several cases it might have struck the reader that a high temperature with a correspondingly bad general condition followed the marrow nailing. These

general reactions are certainly not due to the marrow nailing itself, for they often may be observed in the case of far easier operations, as for instance after a simple reduction by use of a wire extension, and after applying a plaster cast. When surveying all our cases of marrow nailing we must state that these general reactions subsecuent to an operation of the bone are far less frecuent in cases of marrow nailing than in cases of other methods of treatment. Similar observations were also made in other quarters, as FHALT for example pointed out recently.

In cases of osteotomies and compound fractures the reason for these effects is obviously to be found in the fact that we have to deal with more or less numerous bone necroses caused by the absence of periosteum. They are a good culture medium for bacteria. The injury to the marrow obviously plays a far less important part in this case. This point of view is confirmed by the examinations and observations concerning the resistance of bone marrow to infections, as was pointed out in the beginning. In this connection it is interesting to learn that, according to FHALT, the suppuration starting from an infection of the fracture site even with badly infected fractures extends 1 to 1½ centimeters into the bone marrow at the most.

But what about the marrow nailing if an infection of the fracture or of the place of the osteotomy arises? Does a progressive infection of the marrow develop around the nail with all its unfortunate effects, in short: Does a traumatic osteomyelitis or ostitis develop in this way?

We can examine this question by means of the development of two particularly severely infected cases. We refer to cases 9 and 10 which we have described in detail, a compound fracture of the lower leg with a large wound in the soft parts which was not treated until 24 hours after the accident, and a compound supracondylar fracture of the femur, in which a severe infection of the joint followed the entrance of the nail into the knee-joint along a fissure which had not been recognized in the beginning.

The anatomical preparations show a strongly demarcated inflammation in the bone. No mass infection of the marrow with suppurative decay affecting the compacta and the periosteum developed. The picture of the infection, to be observed here, differs from the more or less typical development of an inflammation of the bone marrow in other respects. Apart from the place of fracture, the inflammatory processes are here limited to the bone marrow. In the bed of the nail the bone marrow had decayed suppurativelv and we find an inflammatory granulation tissue, which is highly permeated by hemorrhages and cells of inflammation. In its marginal zones this granulation tissue shows an organization of connective tissue, which is steadily growing stronger towards the periphery. In this way a compact connective tissue coat develops. This is shown quite clearly in case 9.

Near the corticalis we here find moreover a newly formed bone plexus. Distal to the place of fracture on the corticalis and the periosteum nothing astonishing is found. There is no sign of an ostitis or periostitis. In the area of the fracture too the signs of a limited inflammation are clearly seen. In the microscopic sections one can also recognize a well constructed intermediary callus and periosteal callus (case 9 and 10) which could not be demonstrated by an X-ray. Also in the clinical aspect the fracture was not firm. As a result of limited inflammation in these two cases we see finally (as in case5) ring-or crown-sequestra developing in the area of the fracture. This fact should be stressed particularly at this place.

As a general rule, this form of sequestrum can be observed neither in the case of an inflammation of bone marrow nor in one of suppurative fractures. There is obviously no doubt that the development of these sequestra was caused by the marrow nailing and at the coincident infection. By the accident itself, by the haematoma or by the suppuration the periosteum of the fracture had been lifted off from the bone. If the marrow is then injured by the nail and the infection, the compacta must decay, as it is now no longer nourished neither from the inside nor from the outside. The conditions for a development of this co-called ring-sequestrum are particularly found following a marrow nailing and the ring sequestrum may therefore properly be called a typical injury due to nailing. By way of comparison we would remind the reader of the ring- or crown - sequestra which arise in cases of amputations where the periosteum is stripped off too far on the outside while the marrow inside is removed too freely with a currette.

When we supplement these findings obtained by anatomical examinations with the rest of the hospital reports concerning cases of infections, we can picture to ourselves the development of an infection on the bone with marrow nail inserted into the bone as follows:

If an infection arises in cases of closed fractures - which happens only very rarely - it usually causes only a mild, locally limited suppuration of the place of introduction of the nail. The suppuration does not extend to the bone marrow. In some exceptional cases an infection due to unfortunate circumstances (as for instance severe injuries, difficulties in fixing the fracture and so on) may penetrate deeper along the marrow and may thus appear as a suppuration of the hematoma of the fracture, of the ends of the fragment, or of joints adjacent to the affected place. A picture of a pyemic condition, as shown in case 3, may be regarded as extremely rare.

In the cases of an operative treatment of fractures, a case which has become very rare by the improvement of the marrow nailing method, as well as in cases of compound fractures and of osteotomies, one can observe an extension of the inflammation to the marrow correspond-

ing to its high sensitiveness with regard to an infection. The inflammation, however, remains usually limited to the bed of the nail in the marrow. The high immunobiological qualities of the bone marrow, observed by the specialists mentioned in the beginning, can be confirmed again here. It was to be feared that in complicated cases an acute massive inflammation of the bone marrow effecting the compacta and the periosteum might arise, if the nail is driven in, as it renders all parts of the marrow accessible to the germs. This is, however, surprisingly enough not the case. The marrow shows a pronounced tendency to demarcate the bed of the nail quickly with granulation tissue, which soon changes to connectinve tissue and envelops the nail. It is only in the area of the fracture site that a sequestration that is an extension to the corticalis and the periosteum can be found. Here several small-sized sequestra may occur, obviously according to the degree of the infection and the extent of the repeated injury (two cases), or "nail-specific" ring-shaped sequestra may develop (three cases). The tissue of the corticalis and of the periosteum not surrounded freely by pus reacts by forming sufficient callus after the removal of these sequestra. Recently EHALT also directed general attention to the suppuration of the place of introduction of the nail and of the place of fracture combined with occasional separation of small sequestra.

In discussing the question of callus formation in our cases we are going to use the results of our examination of microscopic sections again. In case 9, the preparations showed an endostal and periostal callus formation after the removal of the crown sequestrum in the zone of the demarcation. In the clinical and in the X-ray picture this could not be seen. However, as it was a case of a fresh callus with well formed osteoblasts, it is probable that it would have in time grown more firmly. This observations shows that even in cases of suppuration of long duration and of an inserted nail the new formation of bone does not cease.

In all other respects the callus formation varied, as was to be expected.

In four cases the callus formation was pronounced (case 2, 4, 5 with crown sequestrum and 7), it was normal in two cases (cases 3 in the beginning, now a spotty calcium dislodgement, case 6), in three cases it was delayed (case 8, 11 and 12) and once it was very intense in the beginning and ceased later on (case 13); finally three times in cases of the formation of sequestra, amongst them two crown sequestra during the time of observation, (8,14 and 29 weeks,, which could not be recognized in the X-ray. After a period from 5 to 51 weeks the fractures were clinically firm. The following chart gives the details:

Case	Location of the fracture	Sequester	Callus formation.	removal of the nail	Fracture firm after
1	leg = tibia	-	-	-	-
2	thigh = femur	0	very good	5 weeks	5 weeks
3	leg	0	good i.the beginning	3½ weeks	6 weeks
4	leg	(+)	very good	16 weeks	16 weeks
7	leg	0	good	21 weeks	21 weeks
5	thigh	+ +	good	26 weeks	26 weeks
6	arm above elbow=humerus	0	normal	not remov.	6 weeks
8	leg	(+)	delayed	10 weeks	51 weeks
11	leg	0	delayed	37 weeks	37 weeks
12	arm above elbow =humerus	0	delayed	not remov.	?
13	forearm	0	delayed	not remov.	?
9	leg	+ +	ceased	14 weeks	amputat
14	thigh	+ +	ceased	25 weeks	amputat
10	thigh	+ +	ceased	- / -	amputat

In all these cases, which were observed for a long time, no pseudarthroses arose. Case #13 is suspicious in this respects, as the formation of callus did not make any further progress in the end. We have our doubts about this case, for we had to make the experience here that a thin nail for the forearm with only one bone (the second was missing) near the joint is not able to create the favorable mechanical conditions necessary for healing.

The fact that a formation of callus did not set in, in the beginning is closely connected with the often observed delayed callus formation in cases of compound fractures, (BOERMA, LAUCHE, GOETZE,) for which local causes are responsible. The main cause, however, will be found in the infection. Also the absence of the hematoma which drains off considerably in case of a compound and exposed fracture, is regarded as the cause of this delayed callus formation.

It is, however, still an open question, if and in how far the nail is of influence on the new formation of bone in case of a discharging fracture. As can be seen in the chart the findings in this respect vary. In all our cases, which were generally serious, the irritation produced by the foreign body varies with the irritation of the inflammation. It might be difficult to decide which of the two plays the more important part. It may be interesting in this connection that KOENIG and FICK do not ascribe any harmful effect on the callus formation to the foreign bodies. They are of the opinion that the irritation produced by the foreign body first caused an increased absorption of callus while later on it stimulates an increased formation of the callus.

It should be mentioned here, that we could observe the fine tissue-like formation of callus around the nail as well as the formation of fresh endosteal and periosteal callus in the area near the fracture as well as in the area distant from it, in case 9, a compound fracture of the tibia.

One might suppose that a firm formation of bone (a firm bony healing) might still have resulted. Incidentally, KUENTSCHER ascertained in his experiments performed on animals, an extremely intensive endosteal bone formation caused by the influence of the nail. KOELSCH made similar observations. He saw marrow bone developing around a V2A-wire rod which was inserted sideways. The quick stabilization of the simple nailed fracture is first of all based on the fact that particularly favorable mechanical conditions are created by the marrow nail. Above all, lateral dislocation is eliminated so that the pressure which stimulates the callus formation can develop fully.

Generally the same mechanical conditions prevail in case of a compound nailed fracture. The infection, however, prevents the development of these forces. Under special circumstances it demands treatment with a splint as a matter of course from the very beginning. Thus early movement of the broken limb otherwise made possible by the inserted marrow nail, a condition stimulating the callus formation, will not be possible. Obviously differences in age play a certain part in these cases, as we can see for instance in case 5, an operatively treated fracture of the femur of a boy 7 years old. In this case a quick and intense periosteal callus formation rose by which the fracture cleft was closed, in spite of a severe suppuration and the development of a crown sequestrum.

The above mentioned observations and experiences, not entirely based on a uniform method of treatment, which were gained in the course of the trial of a new method of treatment, enable us in the end to give information on some questions of practical importance.

The cases of compound fractures which can be nailed will first of all have to be carefully selected, as KUENTSCHER has also pointed out recently, in every case fresh fractures which are not too contaminated. Older fractures and those which may have become infected already, seem to be unsuitable for this treatment.

The surgeon unskilled in marrow nailing operations should treat only the more simple cases in the beginning, and should only attempt to treat such complicated cases as his experience increases.

The Clinic at Kiel obtained good results with the marrow nailing of compound fractures (and osteotomies). Recently EHRLICH and EHALT also reported very favorable results.

The surgeon who decides to make marrow nailings of osteotomies and of compound fractures must first of all see to it that all soiled, dirty wounds are subjected to a careful debridement or if this is impossible that they remain exposed. All inflamed parts must be opened widely. It is the method of marrow nailing in particular which now offers such an opportunity in cases of bone injuries.

In no case should the marrow nailing be done several days after the injury has occurred. This is clearly shown by case 7 with its severe clinical picture following the late marrow nailing.

If possible marrow nailings should be performed immediately after the injury. If the general condition of the patient prohibits such an operation during the first 8 to 12 hours, the marrow nailing had better not be performed at all.

The cases of HEIM, shown by KUENTSCHER, during the session at Vienna in July 1942, 2 fracture of the thigh and one gunshot fracture of the arm above the elbow, proved that a marrow nailing can be performed successfully even some weeks later. One can well imagine that the nailing will be early endured by the patient, if the body can dominate the suppuration and the infection has reached the so-called "cold state".

Also in the case of a primarily healing fracture, a suppuration might under special circumstances develop at the place of insertion of the nail or at the place of fracture or at both places some weeks later. These suppurations remain locally limited and no progressive inflammation of the marrow with a severe sequestration is to be feared. After a wide exposure of these accumulations of pus, the nail acts as sort of drain, in the channel of which the pus can drain off (see case 9).

If possible, the nail should be left in its place till the firm healing of the bone, although the severe suppuration might again and again tempt the surgeon to remove this big foreign body. In cases 4, 7, and 8 the suppuration was of long duration and intense. In case 7 a strong involucrum as well as ring sequestrum formed during an intense suppuration around the nail, so that the nail was removed only after a firm bony healing, as mentioned in the other cases above.

In case 8 the severe suppuration stopped. The nail with its center piece even projected out of the wound, which slowly got smaller. It was removed only because it could not fix the upper fragment. As the suppuration was very severe in case 9, the nail was removed prematurely after 12 weeks. Similar was the course of healing of a compound fracture of the femur which we nailed outside the clinic and which was badly dislocated after the removal of the nail (10 weeks after the nailing). This fracture healed in a bad position.

A suppuration may decrease after the removal of the nail (see cases 7 and 9), the suppuration also decreases, however, in cases where the nail is still fixed in the bone.

The diadvantages of a premature removal of the nail are above all the fact that the fracture is moved, furthermore a renewed shifting might arise under special circumstances and the inflammation might be reactivated or increased on account of this mobilization. We have therefore reached the conclusion that the nail should if possible, not be removed until the firm bony healing of the fracture. The nail will be removed only if threatening general symptoms should arise, that is if a long and in-

tensive suppuration sets in. All this, however, has to be specially decided in each individual case. It is not advisable to remove the nail after some weeks, as the suppuration is in such a case maintained only to an unimportant extent by the nail.

If possible, sequestra and the sometimes developing crown sequestrum should remain until a complete demarcation. Also in cases of an inserted nail their removal will be easily managed. The further process of healing is not affected by the development of a crown sequestra, as case 5 shows. Small sequestra are without importance, they can easily be removed.

The fixation of the fracture pieces guaranteed by the marrow nail plays an important part, especially in cases of an infection, since an additional plaster cast would deprive most of the important advantage of accessibility to all areas and on all sides, which is necessary for the early operative treatment of suppurations.

In addition to the above mentioned treatment a plaster cast may be applied for the first eight days under special circumstances, in order to keep all joints in the area near the fracture in a resting position. The most important thing, however, is the "inner splinting" and therefore the fixation of the fracture by the marrow nail. This cannot be obtained by any other method of treatment and represents a highly important factor in fighting any inflammation in the case of an infected fracture.

B I B L I O G R A P H Y

BOERMA	Arch.klin.Chir. 176 (1933):666
BORDASCH	Dtsch.Z.Chir. 253 (1940).
EHALT	Mschr.Unfallhk 47 (1940)Zbl.Chir. 1942,47
EHRLICH	Wien, med. Ges. Juli 1942
ERB	Dtsch.Z.Chir. 218 (1925).
A.W. FISCHER	Kongr. d. Dtsch.Ges.f.Chir.Berlin 1940
A.W. FISCHER u. MAATZ	Arch.klin.Chir. 1943
A.W. FISCHER u. REICH	Zbl. Chir. 1943, 8
FICK	Arch. orthop.Chir.28 (1930): 689
GOETZE	Arch.klin.Chir. 148 (1927):59
GROGON	Chirurg 1927
HENKE-LUBARSCH	Hdb.d.spez.path.Anatomie Bd IX,3
KIRSCHNER	Chirurg 1941
KOELSCH	Dtsch.Z.Chir.246 (1936):641
KOENIG	Die Chirurgie der Knochenbrueche Berlin 1931
KUENTSCHER	Chir.Kongr. Berlin 1940 Zbl.Chir. 68 (1941):857 Chirurg 1942,6, Zbl.Chir. 1942,47
NORDMANN	Kongr. d.Dtsch.Ges.f.Chir.Berlin 1940
LEXER	Lehrb.d.Allg.Chir.Bd.I.1934
LOOSER	Schweiz med. Wschr.58,6:125
TEICHERT	Zbl. Chir. 1924
RAISCH	Wien med.Ges. Juli 1942

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From the Surgical Clinic of the University of Kiel
(Director: Prof. Dr. A.W. FISCHER)

HOW GREAT IS THE DANGER OF OSTEOMYELITIS WITH MARROW NAILING OF COMPOUND FRACTURES?

by

Prof. Dr. A.W. FISCHER and Dr. HORST REICH

with 6 illustrations*

*The microscopical views could not be reproduced.

Reprint from
ZENTRALBLATT FUER CHIRURGIE, 1943, Nr. 8
Edition: Johann Ambrosius BARTH in Leipzig
printed in Germany

Translation prepared by
Office of Military Government for Germany (U. S.)
Office of Naval Advisor
Medical Section

At the Congress for the German Society for Surgery in 1940, the method of marrow-nailing of fractures of the tube-bones developed by KUENTSCHER was announced. In the two years since that time this method has been tested in many clinics, and the publications and reports which consider it to be an ideal method continue to increase.

This new method of treating fractures is quite different from other methods of operative treatment of fractures used previously. The fracture-site does not have to be opened. The KUENTSCHER-nail is introduced into the marrow-cavity at a distance from the fracture through a small stab incision. The fragments are strung (as pearls) on the nail. The shape of the nail corresponds to the shape of the marrow cavity, and its caliber is chosen according to the diameter of the marrow-cavity. This gives an excellent fixation of the ends of the bone so that the shearing effects, which prevent the development of callus, are eliminated.

In 6 out of 200 cases we observed an infection at the place of insertion. There was a mild inflammation of a local character while the nail was in a recumbent position. We have never seen a suppuration extending along the marrow cavity.

After the KUENTSCHER-nailing was proven quite satisfactory in the cases of closed fractures of the shaft, this method was used for open fractures as well. This decision was a very responsible one as there were many factors to be considered.

The certainty of an exact repositioning and of a firm fixation of the fragments resulting from the use of the marrow-nail were factors which are generally acknowledged as favorable for defense against infection. Because of this we considered the use of the method as an acceptable one in open fractures. Furthermore, we remembered that the marrow of the bone shows little tendency to become infected according to the investigations of LOOSER, LEXER, W.MUELLER, ERB, and BORDASCH, and that the marrow obviously possesses considerable resistance. Finally we expected to achieve a more rapid union in good position, and thus better success, combined with a more rapid course of healing than we are ordinarily accustomed to observe in cases of infected fractures.

Our main question was: How does the infected bone-marrow, in the case of compound fractures, react to a large foreign body as represented by the marrow-nail? Does a progressive infection of the marrow develop around the nail with all of its disagreeable consequences? In short, does a traumatic osteomyelitis or an ostitis arise?

To a certain degree we could use the experience gained in the operative treatment of open fractures where metallic foreign bodies were introduced. This method is characterized by the use of a nail of small dimensions as compared to the marrow-nail, and which either not at all or only partly touched the marrow-cavity. The use

of metallic foreign bodies has been warned against, especially in cases of severe infections. In cases of infected fractures GOETZ recommended that any foreign bodies be as small as possible. Generally, the degree of the infection caused at the time of the injury was the decisive factor determining the operative or clinical treatment of the fracture. This rule was not suitable for an absolute indication in every case. The course of an infection does not only depend on the quantity of the germs introduced but it depends as well on the special kind.

Because of all these considerations it can be concluded that the marrow-nailing of complicated fractures should be regarded as something quite different and should not be compared to the earlier methods of treatment.

In the beginning there was no possibility for a decision as to whether or not the new method would be a progress, and we could do nothing but make experiments with men, groping step by step. Otherwise we could not form an opinion.

We now have available considerable experiences which MAATZ and REICH will report about later. In the present work we shall report three observations as being especially important for the study of the extension of an infection in the case of marrow-nailings.

Case 1: R.E., woman, 51 years old, Hospital-report Nr. 1608/1941

She was sent to the hospital on the 30th of November 1941, with a complicated supracondylar fracture of the right femur. The proximal fragment of the fractured femur jutted out about 8 centimeters, at a place about 10 centimeters above the knee. On the front side we saw a deep wound in the soft tissues about an inch in diameter. On both sides of the joint there was an extensive abrasion of the skin. The knee-joint was not exposed so that it could be inspected. The extensor muscles were damaged.

Excision of the wound and approximation sutures. Drainage of the remaining cavity to both sides. Sutures of the tendons. Freshening of the bone and of the proximal fragment which juts out. Reposition of the fracture and marrow-nailing (KUENTSCHER) to prevent the angulation of the distal fragment. Plaster cast applied.

During the following days the temperatures increased slightly. We made a cast with windows around the hips. We saw a more intense suppuration after a fortnight, finally high temperatures, an intense disturbance of the general conditions of the patient. Following large doses of "Globucid" (a sulfonamide) the temperature temporarily decreased to subfebrile values. In the meantime a control X-ray on November 4, showed that the nail had penetrated into the middle of the knee-joint, separating the two condyles. This happened through a fissure

line which extended into the joint and which was not observed previously. Revision of the wound after a new rise of temperature. The knee-joint, which had become infected was opened on December 2, because of a septic clinical picture with a considerably worse general condition. Amputation of the femur. On the next day: exitus.

Bacteriological finding: Hemolytic streptococci.

Illustration could not
be reproduced

Ill. 1. shows the post mortem specimen of the amputation. We can see the separated femur-condyles and the place of the supracondylar transverse fracture with a sequestrum - in the shape of a ring or a crown - at the proximal end of the fracture. This sequestrum was clearly distinguished from the other part of the bone by its white colour.

The following preparations were examined microscopically:

1. parts of the fracture-site with bone marrow and nail-bed,
2. cross-section of the femur at a place above the fracture. The preparations were stained according to the technic of vanGIESON with sudan after they had been decalcified with hematoxilin eosin.

At the fracture site (nail-bed) we find fibrin and a small zone of non-specific inflammatory granulation-tissue which is very clearly differentiated by a hyperemic marrow-tissue of large and small meshes, with perivascular infiltrations of small-cell character. In the reticulum, the cells of which have a large plasma-substance and small intensively stained nuclei, we see large, obviously fat storing, histiocytes. Adjacent is a zone of newly-developed little slivers of bone with clearly marked lines of osteoblasts. The marrow-tissue here shows intense hyperemia and relatively numerous diffused, small-cellular elements, edema, and large histiocytes as well. The poly-nuclear elements are less numerous.

In the cross-section of the femur above the place of the fracture we see in the nail-bed a small stripe consisting of blood and masses of fibrin, both of which contain cells of inflammation. Here the marrow-structure has been lost. A distinctly outlined, non-specific inflammatory granulation-tissue lies adjacent. Finally we see marrow-tissue with small and large fat-islets with more or less diffuse small-cell perivascular infiltrations, smaller haemorrhagic areas and extraordinarily intense hyperemia. Adjacent is the completely normal large compacta zone and the periosteum without signs of an ostitis or periostitis. There is no extension of the inflammation through the canals of HAVERS and there are no abscesses.

Microscopical view
could not be reproduced

Ill. 2, Cross-section of the femur. No marrow-phlegmon. Inflammation limited to the former nail-bed.

Case 2: W.J., peasant, 60 years old, hospital report Nr. 2606/1942.

He was sent to the hospital on January 28,1942, with a complicated fracture of the right leg as a consequence of having been run over. Accident 24 hours before. A smooth transverse fracture of the right tibia (with a fracture of the fibula) at the junction of the middle and the lower third. The case was complicated by a large dirty wound of the soft parts, evident only on the surface. Great hematoma in the lower third of the leg. Under evipan-anaesthesia the marrow-nailing is performed without difficulty. As the nail does not fix the lower fragment firmly enough, a cast with windows is applied. Post-operatively the temperatures are irregular, but they rise only once to 39 degrees (Celsius). The wound begins to suppurate, and the adjacent parts swell. On February 7 we see to our surprise that the soft parts having been damaged when run over, have become necrotic down to the bone. Now follows a large excision of the wound in order to expose the beginning phlegmon.

February 28. Once more revision of the wound with a counter incision and drainage.

March 3. Reddening and swelling at the place of insertion of the nail which primarily had been well. As a consequence we see a very intense suppuration at the incision which continues in the following weeks. It was less intensive at the fracture site.

April 4. Removal of the marrow-nail in the belief that it maintained the suppuration. The suppuration decreases but does not stop completely. It is maintained at the tuberosity by necrotic tendons. This lasts until the necrotic portions are excised. The fragments can still be moved freely.

April 23. Wire extension through the calcanous in order to prevent a shortening of the leg.

May 7. The X-ray picture does not show any formation of callus. On each of the two ends of the fracture, there are ring sequestra. Sequestrotomy: The dead bone-rings had not yet been completely marked off by the healthy bone so that they had to be removed by the use of a LUER's rongeur.

As the patient was very impatient and anxious to be healthy soon in order to work on his farm, and considering his wishes, we agreed, on May 21, to an

amputation of the leg, 12 centimeters below the knee-joint. The wounds remained open. Reconvalescence per secundam. With an auxiliary prosthesis he was released at the beginning of July.

Illustration could
not be reproduced.

Ill. 3. Complete fracture of the lower leg after removal of the nail. Crown-shaped sequestrum.

Macroscopic examination of the amputated bone-preparation: When all soft parts had been removed the tibia did not show any peculiarities on its outside, except at the site of the fracture. Up to that place the sheath of the periosteum envelops the tibia smoothly and does not show any extraordinary elevated areas or abscesses.

The fracture site is bridged over only by connective tissue. When we cut into this tissue with a knife, we hear grating, so evidently bone-residues or calcified parts are present. The bone is now opened by means of a saw for its entire length. We see that above as well as below the site of the fracture the compacta and the spongiosa have remained normal in so far as we consider the surface. In the preparation we see clearly that toward the inner parts and toward the marrow-cavity the compacta is lined by a layer 3 to 5 millimeters thick of uneven connective tissue. This lining is continued by a rather soft marrow above as well as below the fracture. The bed of the marrow-nail in the marrow-cavity appears completely suppurative. The same appearance is found in all areas.

In the cross-section we distincly see a central hole with a diameter of 2 millimeters for the entire length of the marrow. At the ends of the fracture the bone-marrow is missing; here we find intermediary depositions having the character of connective tissue. We cannot decide, macroscopically, how far the formations of bone extend. It is extraordinary that the compacta on its surface, shows a completely normal constitution; aside from the irregularities of the compacta caused by the fracture. The area of the spongiosa, adjacent to the ankle-bone, does not show anything unusual either, and nowhere are there any sequestra. Everywhere we recognize formation of small slivers, and nowhere is there an increased porosity or formation of sequestra.

We do not propose to discuss the conditions of the soft parts in this article.

Microscopical view
could not be reproduced

Ill. 4. Fracture-site of a complete fracture of the lower leg with inflammation of the central marrow. Formation of a capsula of connective tissue in the area of inflammation. Intermediary and periosteal callus formation. Normal compacta.

Microscopic examinations of the tissue: We examined the fracture-site: further we examined various places for a distance of about 10 centimeters above the location of the fracture in cross-sections as well. The preparations were treated as mentioned above.

Microscopic analysis of the fracture-site: The marrow tissue is missing from the central zones. Here we find a tissue markedly infiltrated by small-cellular and also polynuclear inflammatory elements. In this tissue we also recognize numerous, partly enlarged vessels with a smooth membrane completely filled with blood, and masses of fibrin. This examination has to be made at the places which are directly in connection with the marrow-nail. It is extraordinary that here we find only a small concentration of the inflammatory elements related to the formation of suppuration-foci. This tissue, representing a granulation-tissue containing inflammatory elements, changes more and more - the closer we approach the marrow-periphery - into a typical granulation-tissue in which we find numerous histiocytes obviously storing fat.

This granulation-tissue which in general is loose, changes into a connective tissue becoming more and more compact. In the latter we find the inflammatory elements in the form of perivascular infiltrations of predominately small-cellular character. The vessels have thick membranes here. We find a distinct decrease in the amount of the inflammatory infiltration. Here one finds the picture of a demarcation of the marrow-parts, inflammed in the central portion with a capsule of connective-tissue becoming more and more dense towards the periphery. Inside this capsule large areas are hyalinized as well. In the marginal-zones of this capsule we recognize the formation of new bone with the character of marrow-callus. This picture is much the same up to the site of the fracture. The small new-formed slivers of bone show a normal configuration. We are dealing with an endosteal marrow-callus and intermediate callus. Adjacent to this bony substance we see the zone of the tibia compacta with a completely regular bone-formation, and there are no pathological modifications. Directly adjacent to the fracture-site the canals of HAVERS are enlarged and contain small-cellular elements situated perivascularly. Besides, they contain a small-meshed frame-work with fibrin and vessels. In some canals of HAVERS we observe a more or less distinct formation of bone.

There appears a large zone of periosteal deposits of bone in a considerable contrast to this compacta-zone. In the direction toward the outside we see a dense connective tissue. Here we are dealing with a periosteal callus.

Microscopical view
could not be reproduced.

Ill. 5. Formation of callus in the peripheral marrow area distant to the fracture-site

Microscopic analysis at a place distant from the place of the fracture: In respect to the microscopic character of the tissue we generally have the same inpression in the cross-section, except that the periosteal reconstruction of bone is missing here. A small difference is that the single tissue structures described above show, in the direction from the inner parts to the outside, a much more distinct differentiation from each other. The most central parts of the marrow have changed into an inflammatory granulation-tissue, which gradually becomes more and more loose and changes to a dense layer of connective tissue, in which the cells of the inflammation are less common. In the zone of the periphery of this layer we find, here too, distant from the place of the fracture, an endosteal reconstruction of bone in the form of well-defined small slivers. Adjacent to this we find again the large compacta-zone and the periosteum. Neither shows anything unusual.

Recapitulating, we have the impression of a suppurative inflammation of the central parts of the bone marrow being restricted to the area of the former nail-bed. In the peripheral part of the marrow this inflammation has been demarcated by granulation tissue so that a dense layer of connective tissue has developed. Only in the zone of the fracture site does the marrow show a more intense infiltration. Nowhere do we find a real abscess, and in no case does the picture of a marrow-phlegmon with a total destruction of marrow appear. Compacta and periosteum have not been affected by the inflammation. An active reconstruction of bone, in the sense of a periosteal deposit in the area of the fracture, can be seen. We also find a dissolution here, but chiefly we observe reconstruction. There is a formation of inermediate and marrow-callus. The latter is also formed at some distance from the fracture, in the peripheral part of the marrow.

In the cases about which we have reported before, we were dealing with complicated fractures with intense infections. The third case we have to discuss, differs from these. Here we had to expose the fracture-site because of the interference of muscles laying between the broken bone-ends; and an infection had developed. The clinical course of this case and the resulting observations are, so-to-speak, a continuation of the above observations. Therefore we describe this case as well.

Case 3: W.K. boy, 7 years old, hospital report Nr. 3436/1941

This boy was sent to the hospital on March 20, 1941, with a simple transverse fracture in the middle of the right femur. On March 24, we performed a marrow-nailing by exposing the fracture-site, as a non-operative reposition had no success due to the interference of muscles between the broken bone-ends. He had a third degree burn on the left thigh due to the heat from the X-ray tube. Later on the temperature increased. We considered this to be caused by the inflammation brought about by the burn.

April 9. The patient was sent to the Schleswig-hospital (a mental hospital). (He was a Mongolian idiot). On May 9, the patient was sent back to our clinic as a large abscess had developed on the inner side of the right thigh. It was opened widely and drainage followed. May 31, the X-ray showed that there was no sequestrum to be seen. After the temperature had been temporarily irregular, the suppuration became less intensive. We found hemolytic streptococci. A cast with windows at the hips was applied. In the following period there was suppuration of two fistulas on the outside and inside of the right thigh. On September 23, we made an X-ray picture: In the area of the osteotomy a sequestrum in the shape of a ring or a crown, nearly as large as a chestnut could be seen. The adjacent parts of the bone were atrophic. Round the sequestrum we found a distinct large periosteal formation in the form of an involucrum. November 7: sequestrotomy and removal of the nail. We had to deal with a sequestrum in the shape of a cylinder, and we could remove it without difficulty. A correspondingly large cavity remains. November 14: once more revision. On March 9, 1942: The wounds have closed, except for small fistulae. The fracture was stabile. Our patient got up on March 15. and was sent home on April 11 with a very small fistula located on the side of the thigh, which was secreting very little.

Recapitulation:

We are here dealing with osteomyelitic conditions as the clinical course and the anatomical investigations show. Twice these conditions have arisen as a consequence of infected and complicated fractures. In the third case such a condition was the result of an infection of the exposed fracture-site. We must seek an explanation for the especially unfavorable course of the first mentioned case concerning a complicated supracondylar fracture of the femur. We point out that there was a massive infection of the knee-joint when the marrow-nail penetrated into the joint by way of a small fissure, which we had not recognized on the X-ray picture. Thus it created a wide-open communication between the infected fracture site and the knee-joint.

In the second case there was a complicated fracture of the leg with a large wound of the soft parts. This fracture was treated only 24 hours after it had occurred. Whilst in the first case we had a period of nine weeks for observation, we could observe the second case for a period of five months. The anatomical preparation in the second case was removed 13 weeks after the treatment began.

In the third case we were able to observe the process of healing for 13 months. In the last case we can judge only by the clinical results. In both the former cases we have the anatomical preparations at our disposal. These enable us to study the course of the development of the infection in cases of marrow-nailing of complicated fractures by microscopic methods as well. A prejudiced observer would be prone to make the large nail responsible for the course observed.

From a clinical standpoint alone the disagreeable course of the cases is not at all an unusual one, as they concern two difficult and complicated fractures and in the other, a compound fracture. These are cases in which an unsatisfactory course is not at all surprising or remarkable. It is only the use of a new method for the treatment of fractures by means of a large metallic foreign body introduced into the marrow-cavity, which makes these cases remarkable in a scientific respect.

As a common factor of the anatomical preparations we mention the impression of an intense demarcating inflammation in the bone marrow. There has not been any massive marrow phlegmon with a suppurative decomposition of the marrow.

Also the impression which we get here differs from the more or less typical course of osteomyelitis of youths in other respects. Here the inflammatory processes are restricted to the bone-marrow, without any relation to the fracture-site. In the nail-bed the bone-marrow is decomposed by an infective process. Here, after nine weeks in one case and, still more distincly, after 13 weeks in the other case, we find an inflammatory granulation-tissue which is intensely infiltrated by haemorrhagic areas and cells of inflammation. Inside its peripheral zones this granulation-tissue shows more and more intense organization with the character of connective-tissue. Thus a solid layer of connective-tissue develops at last, as is demonstrated in quite an impressive way by the second case. This layer is characterized by its showing the formation of new bone (marrow-bone) with a frame work like character in those parts adjacent to the corticalis. We cannot observe any peculiarities of the corticalis or the periosteum at a distance from the fracture-site in either a macroscopic or a microscopic respect. There are no signs of an ostitis or of a periostitis. Also in the area of the fracture we find very distinct signs of a demarcated inflammation. Besides, the microscopic preparation shows here a new intermediary and periosteal callus of a well-formed constitution (case 1 and 2). In the roentgenographical respect, case 3 shows an intense periosteal new bone formation at the

fracture-site. In the two former cases (1 and 2) the roentgenogram did not demonstrate this callus. In the clinical respect the fracture-site was not fixed in case 2. We have seen in all three cases, that in the area of the fractures, sequestra in the shape of rings or crowns developed as a consequence of demarcating inflammations. This fact must be considered as an important one.

In general we do not observe such kinds of sequestra either in cases of osteomyelitis or when we have to deal with an infected fracture. There cannot be any doubt about there being a relation between the development of the sequestra and the nailing, and, at the same time, the infection. The periosteum of the ends of the fractured bone was removed either as a direct consequence of the accident, or by the hematoma, or as a result of the suppuration. In addition, if the marrow is damaged by the nail and by the infection, the compacta must perish as it is no longer nourished from within nor from without. These conditions of the development of the ring-shaped sequestra are particularly apt to exist in cases of nailings; and therefore we can consider the ring-shaped sequestrum to be a typical evidence of damage by the nail. Making a comparison we draw your attention to the ring- or crown-shaped sequestra which appear in cases of amputations, when the periosteum is removed too far on the outside and when the marrow is curretted away too much inside.

The microscopical preparations, which we have obtained after the crown-sequestrum had been removed in case 2, show endosteal and periosteal formations of callus in the zone of the demarcation. Since the microscopic examination shows we are dealing with new callus with well-formed osteoblasts, we are entitled to believe that there would still have been a consolidation. In all cases we missed an early formation of callus, and we consider that a relation exists between this fact and the retarded formation of callus which we observe in other cases of open fractures. We have to consider the infection to be the main cause for this. BIER and MATTI believe the absence of the hematoma, the greater part of which drains out in cases of open fractures and operative treatment of fractures, to be responsible for this fact.

There is really only one question, whether the marrow-nail being a foreign body, had hindered the formation of callus or not. In the described cases there is a simultaneous occurrence of an intense inflammation and the influence of the foreign body, and therefore we cannot decide the question precisely. Speaking about this we consider it interesting that KOENIG and FICK do not agree to the conception of a disadvantageous effect of foreign bodies in respect to the formation of callus. They say that the irritation of the foreign body firstly produces a more intense decomposition, but then an intense restoration.

As to the above-mentioned formation of marrow-callus in zones of the marrow adjacent to or distant from the fractures, we call your attention to the observations of KUENTSCHER concerning his experiments with an intense endosteal formation of callus as a result of a foreign body in the marrow. There is still another observation of KOELSCH that is of interest. During his experiments he observed the formation of marrow-bone round a wire introduced into the marrow-cavity. Of course, it is difficult in our cases, to separate the irritation of the inflammation from that of the foreign body in respect to the formation of callus.

Thus we can say, the remarkable fact in the case of marrow-nailings of infected fractures is as follows: It is true, that an infection of the marrow develops, but it remains restricted to the nail-bed of the marrow. The authors, mentioned above, have observed important qualities of an immunifying-biological character which the bone-marrow possesses; and we find such observations again proven true here. We feared that in complicated cases there would be an acute and massive inflammation of the bone-marrow with an involvement of the corticalis and the periosteum, when the nail is inserted, for the nail opens the way to all parts of the marrow for the suppurative agents. We were very surprised to see that there is not such a consequence. The marrow has a definite tendency for a rapid demarcation of the nail-bed by granulation-tissue; and this envelops the nail quickly while changing into a connective-like tissue. A sequestration, and thus an involvement of the "corticalis" and the periosteum is to be found only in the area of the fracture-site. Here it can - just as described - cause the formation of ring-shaped "nail-specific" sequestra. The tissue of the corticalis and the periosteum, which are not involved in the infection, react with an intense formation of callus after the sequestra have been removed.

We are not entitled, however, to consider the discussion of the details of these three cases, to be sufficient to form an opinion that marrow-nailing in cases of complicated fractures is without danger. To prove this will be the task of MAATZ and REICH, who will report in their work announced above, about the experience concerning the nailing of such fractures. The present work shows clearly that the nail can remain even in the event of an intense suppuration. When the fracture-site is sufficiently wide open, it acts as a kind of drain and the suppuration is drained out by the channel of the nail. The irritation of the inflammation plays an important role in the process of decomposition and restoration. The marrow nail surely does not produce a decrease of the bone-infection but does show advantageous qualities as we already have discussed. In case there are ring-sequestra they may be removed without difficulties after their demarcation.

Bibliography:

BOERMA, Arch. klin, Chir. 176, 666 (1933)

BORDASCH, Dtsch. Z. Chir. 253 (1940)

EHALT, Mschr. Unfallheilk. 1940, 387

ERB, Dtsch. Z. Chir. 218 (1925)

FICK, Arch, orthop. Chir. 28, 698 (1930)

GOETZE, Arch, klin. Chir. 148, 89 (1927)

HENKE-LUBARSCH, Handb. der spez. path. Anatomie 9, 3

KOELSCH, Dtsch. Z. Chir. 246, 641 (1936)

KOENIG, Die Chirurgie der Knochenbrueche. Berlin, J. SPRINGER, 1931.

KUENTSCHER, Chirurgenkongress Berlin 1940. Zbl. Chir. 1941, 857; Chirurg 1942, H. 6.

LEXER, Lehrbuch der Allgem. Chirurgie 1 (1934)

LOOSER, Schweiz. med. Wschr. 58, 125

TROELL, Arch. Klin. Chir. 179, 725 (1934).

Special reprint from: Monatsschrift fuer Unfallheilkunde (Monthly Magazine for the Healing of Accidental Injuries) 50th year No. 7.
Publisher: SPRINGER, Berlin W 9
printed in Germany - SPAMER A. G. Leipzig.

THE INDICATION FOR STABILE OSTEOSYNTHESIS

(MARROW-NAILING METHOD OF KUENTSCHER)

by

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Translation prepared by:

Office of Military Government for Germany (U. S.)

Office of Naval Advisor

Medical Section

The results and advantages of the marrow-nailing method according to KUENTSCHER, at first proposed chiefly for transverse fractures in long tube-bones, were so convincing that it was very soon adopted for oblique and spiral fractures too. The clinic at Kiel now advocates the point of view that every fracture that is suitable for the procedure, should be nailed and we share this opinion based upon our experiences.

The principle of the method is the closed reduction of simple fractures. The marrow cavity is opened at a place some distance from the fracture site, the nail is inserted through it and driven into the distal fragment under X-ray control. The fixation of the fragments is so stabil that in most cases an additional fixation dressing is not required. After 2 or 3 days the patients start motion exercises, and can stand weight bearing after 1 to 3 weeks.

By early motion a stiffening of the joints is prevented with certainty, and the care during convalescence is rendered much easier. Even when the fracture has not yet achieved a bony healing the nail gives such stabil support that the patients can again resume work within 4 to 6 weeks after the operation, according to their occupation. The early use of the limb and the fact that the nail prevents any lateral displacement and any bending effects while it enables all those forces which assist the restoration of the fracture to become effective, favors the formation of callus and simplifies the treatment, and the healing of the fracture. The being free from pain when using the limb, the possibility to use the limb very early and to go back to work after a comparatively short time exert a very favorable psychic influence on the patient who gets rid of the feeling of having been severely injured.

The risk of the method is practically small. As there is no need to expose the site of the fracture one need not be afraid of an infection in the case of simple fractures. Infections have indeed occurred in the place where the nail was inserted, but they have never caused a marrow-phlegmon or suppuration at the fracture site itself. The nails consist of V2A-steel and are always removed after the fracture is healed. Therefore no damage due to the metal need be feared. No disturbances of the callus formation have to be feared, such as occurred in the recently employed method of bolting with ivory or bone splints, because the nail does not fill the marrow cavity completely by reason of its shape and it touches the periosteum at not more than 3 small lines.

The technique of the method will not be explained here, but we want to point out particularly that it is absolutely necessary that the complete instrumentarium is available.

All transverse, oblique,and spiral fractures of the long tube-bones are suitable for nailing if they are located far enough from the joint ends of the bone so that the nail obtains sufficient fixation in the fragment. In case of the femur this distance has to be not less than 7 to 8 centimeters, in the leg and humerus, 4 to 5 centimeters. Linear fractures and spiral fractures in which the fracture cleft reaches close to the joint-plane are not suitable as the bone is liable to burst because of the nail pressure from the inside. Furthermore, in these cases the nail does not obtain sufficient stability and would need an additional supporting cast or splint. A third fragment, however, is not of importance; if it is tube-shaped it will be held by the nail, if it is separated it usually will lay on closely, but one has to be careful in these cases not to use the limb too early.

The absolute fixation obtained without using casts along with the mechanico-biological conditions are favorable for callus formation and make the stabile osteosynthesis advantageous over other methods even when the site of fracture itself has to be opened, as is necessary in an osteotomy done because of a badly healed fracture; in this case the method has another advantage: It is not necessary to remove the periosteum from the bone, but two new surfaces are produced with saw or chisel and the marrow cavity is opened with the drill or awl.

Even large masses of callus adhering to the fragments will be left in the close vicinity of the osteotomy site. It is an important material for bone reconstruction and favors the healing in addition to the mechanical conditions. Exposing the site of fracture simplifies the technic considerably. The extension apparatus necessary for the treatment of the closed fractures and an X-ray instrument are not needed, as the nail is inserted into the distal marrow cavity while visible in the open wound.

In cases of delayed callus formation and old, inadequately restored fractures nailing is proposed only if the fracture has been immobilized long enough so that one may properly speak of a threatened pseudarthrosis, or if the position is so faulty that no satisfactory functional result can be expected. One has to remember that the connective tissue union of the fragments causes much difficulty in the replacement without operation, and that the insertion can even be made impossible if connective tissue plugs the distal marrow cavity. In this case it may be necessary to expose the site of the fracture and thus the hazard of infection is increased. During the war, much more frequently than in peacetime, it is necessary to decide on this matter in small hospitals and in this circumstance, the definite advantages of the nailing method for the treatment of simple fractures, may lead to erroneous decisions in old fractures, if the hazard and difficulties of this operation are not sufficiently considered. Therefore, if the position of the fracture is satisfactory, if angulation and shortening is overcome, no nailing is advised, if more than 3 weeks time has passed after the

accident in cases of leg or humerus fractures, if more than 5 weeks in cases of fractures in the femur. No nailing is advised even when the fracture is still movable and when the X-ray picture does not show any callus formation. A sufficiently long period at rest leads in those cases to good results, as was particularly pointed out by BOEHLER.

In any case of old fractures one should try to obtain results without exposing the fracture. For this means it is necessary to mobilize the fracture widely with force. It is not sufficient to juse the extension technique; if the fibula is already healed in leg-fractures it has to be separated either with an operation or if necessary broken by means of an osteoblast. In this way, however, KUENTSCHER and ourselves have always been able to perform the nailing subcutaneously even in fractures older than 2 months. But the difficulties are considerable, even with the technically simplest kind, namely the nailing of the lower leg.

In case of genuine pseudarthroses, the reasons for their occurring in healthy bones are mechanical ones (except in the infected cases), according to the present day point of view. The stabile osteosynthesis has advantages over other methods because of the favorable mechanice-biologic conditions for formation of callus created with this method.

Exposing the fracture site cannot be avoided as the injured tissue must be removed and the marrow cavity has to be opened. The slight damage to the periosteum, which has to be removed from the bone for only a short distance, and the possibility of maintaining the callus are important factors for the reconstruction. In any case it is important that the nailing may be performed in potential or actual pseudarthroses even when sequestra or fistula exist. Thus it can be done at a time during which no BECK drilling or splint-procedure would be possible. Our own and the experiences in the hospitals in our area have proven this fact. The experiences concern 11 fractures of the humerus which were either still draining or the wounds of which had been closed for only a few weeks, 12 gun-shot fractures of the same kind, and 8 gun-shot fractures with fistula and sequestrum-formation. Among the latter ones was a 2 year old defect-pseudarthrosis with a small sequestrum, which has separated 14 days before, and a persistent fistula. We were able to obtain good results without opening the fracture after the fibula was severed (at some distance from the pseudarthrosis).

It has been widely discussed, whether fresh compound fractures can be treated with an osteosynthesis with plate or wire besides the surgical wound-treatment. FRITZ KOENIG and his followers always had the opinion that the maintenance at rest, in addition to the osteosynthesis, is a greater advantage in the defense against infections than the disadvantages (as they say) of the insertion of the foreign body. The fixation with the marrow nail is much better, may even be so good that the

commonly necessary plaster-cast can be avoided. Therefore we employed this method whenever possible, even in cases of compound fractures. The technique is considerably simplified by the fact that the intervention is made while the fracture site is visible in the open wound. As a matter of course all the general rules for the treatment of open fractures have to be carefully observed (especially drainage of the hemorrhage and most careful surgical cleaning of the wound). It is also very possible that in compound fractures infections can occur where the nail is inserted. This event happened to us only once.

The number of patients treated by ourselves is small and even KUENTSCHER has reported on only 3 cases, but EHRLICH (Zbl. Chir. 1943) has treated more than 40 compound fractures with the KUENTSCHER nail among them even femur-fractures. In all these cases no infection occurred which extended along the nail inside the marrow cavity, and the results were good. Of importance is the fact that all of EHRLICH's cases were from the mines, and included for a great part considerable damage of soft-parts and soiled wounds. However, it sometimes happened in these cases that an infection or sequestrum occurred at the fracture site, but it was never observed that a marrow-phlegmon had formed, nor was it necessary to remove the nail. It was an important consideration that bony healing was always obtained.

EHRLICH, recognizing that it is an advantage to place the injured limb at complete rest, was the first one to have the courage to nail a severely infected fracture of the femur (Zbl. Chir. 1941,1378). Then ZELL at the Air-Force Hospital Rerik nailed a severely infected gun-shot fracture of the femur and not only saved the limb but probably also saved the life of the patient (Zbl. Chir. 1943).

In a hospital of our area the author treated one severely infected fracture of the femur, and in his private practice two similar fractures in the humerus with the KUENTSCHER nail. In all these cases the temperature was elevated for a short time after the operation, but the general condition of the patient grew better very shortly. After the nailing, the patients were completely free from pains and the care for them was very much simplified. In all cases bony healing was obtained, even if some small sequestra have been separated (in the fracture of the humerus, with extensive tube-abscesses up to the arm-pit). Naturally it has to be expected in cases of infected fractures, that under special circumstances the infection can be mobilized. as it occurred to HARTMANN in the case of a fracture in the humerus. An erysipelas developed and sequestra formed in the site of the fracture. The result was good even in this case. It is not decided as yet whether the use of Marfanil-Prontalbin powder in the wound is favorable for the defense against the infection. We believe this procedure can be advised.

The nailing of fractures in the humerus is particularly endagered, because the nailing from the distal end does not obtain such a stabil fixation by the nail as in cases of the femur or the tibia. The marrow cavity of the humerus is extraordinarily wide in its proximal half, and cone-shaped, therefore the nail does not obtain sufficient fixation. It has to be driven into the spongy part of the neck and becomes loose after a while. In that way, even by the weight of the arm, the fracture-cleft becomes wider and thus permits motion. We could observe this in compound fractures (as EHRLICH) in two cases. Therefore we performed the operation for fractures above the middle of the humerus from the upper end of the bone. The nail is driven in from the lower end of the crista tuberculi majoris. The tip of the nail clamps firmly in the marrow cavity which is of conical shape with the tip towards the elbow. The upper part of the nail obtains a firm fit because it is held on one side in the drill-hole of the bone-corticalis, and the other side lies close to the opposite wall (This technique is described in Zbl. Chir. 1943).

As a matter of principle, as plaster-splint cast should be applied in all cases of infected fractures (such as a fresh compound fracture) until the infection hazard is overcome or at least is under control.

The results now available show, however, that the nailing operation is permissable even in severely infected fractures. But caution must be taken that the operation is not undertaken without very careful consideration, as the experience is still quite limited. Nailing seems to be indicated if it is not possible to fix the fracture with the usual conservative measures in such a way that the suppuration can be effectively combatted, or when the sequestrum-formation which caused the suppuration makes it necessary to expose the fracture site anyhow.

An unsatisfactory position of the fracture is not sufficient reason for the nailing. It is better to wait until the acute suppuration has subsided and the wound is healed or has closed except for one fistula. External circumstances can increase the number of cases suitable for the nailing during war time. When for instance a hospital has to be vacated or moved, it has to be considered that the nailing simplifies the transportation of the patiant a great deal. However, it is necessary to keep the patient under the care of the surgeon for at least 8 days after the operation, if possible at the same place.

It is absolutely necessary that sufficient technical skill is available, that the correct procedure is chosen when mailing infected or fistulated fractures. If the nail is chosen too short or too thin, thus not placing the fracture absolutely at rest, if the wounds are not left open or do not drain at the correct place, or if not opened at the correct place, or if not opened immediately when an infection occurs, or if the use of the limb is

started too early, the infectious wound-secretion is sucked and pressed into the marrow along the nail-slot when the limb is moved even slightly, and a marrow-infection will occur. Though this infection usually is chronic and the fractures have healed firmly in the observed (3) cases, it is an "incident of treatment" which could have been avoided and must be prevented in the future.

The good experiences in open fractures, together with those in acutely infected fractures permit one to consider also fresh gun-shot fractures as suitable for nailing if the fracture is not older than 8 to 10 hours and if no evidence of wound-infection has arisen.

> As yet, we have observed only 4 cases of fractures in the tibia by KUENTSCHER (bomb-splinters) and 2 cases of gun-shot fractures in the femur by BOEHLER and HEIM, all of them were healed without complications (except one case of infection at the place where the nail was inserted). But the observations of EHRLICH, whose compound fractures are very much like gun-shot fractures on account of their conditions and prognosis, can be referred to when the usefulness of the method is considered. It is significant that EHRLICH wrote to the author that he "was not forced to drive the nail in after an infection had developed because he employed primary nailing".

Personal experience is important when treating gun-shot fractures. The greater it is, the more can be dared and the better are the results obtained. Absolutely necessary is experience in the treatment of gun- shot wounds in general and the availability of a sufficient variety of nails. A nail too short or too thin can never keep the fracture absolutely at rest and thus the hazrd of infections is increased. Even though the nailing of a compound fracture is technically simple and can be performed without an extension apparatus or X-ray equipment, care must be taken that the wound is not treated incorrectly and thus the hazard of an infection increased, and this danger of faulty treatment also not be increased further by a nailing of the fracture.

Generally it can be said: The fresher the injury is and the more the conditions of the wound allow one to hope for an effective control of the infection by surgical treatment, the earlier is the stabile osteosynthesis advised as this method, in addition to providing absolute rest (thus a means of infection-defense), is able to free the patient immediately from pains, simplifies the care, and,last but not least, provides the best possibilities for transportation.

Especially is this simplified transportation a decisive factor at rapidly changing fronts and with Airborne Medical Troops. A technically correctly nailed fracture does not require a cumbersome cast. The wounded person can be transported without difficulty with a truck, horse-drawn vehicle or sled, in emergency case even with an

autocar or sitting in an airplane, as the motion of the vehicle does not cause any pain to the patient, and no shifting of the fragments (especially hazardous when an infection has to be feared). When considering the fact that in rapidly moving troops and in Airborne Units the fate of a femur-fracture depends very much on the possibility that adequate fixation can be obtained with early evacuation to the rear, one will decide to nail in more cases than usual as, in the femur particularly, the fixation by the nail is very stabile. Thus it is unnecessary to employ any additional fixation bandage. Under those circumstances, even without great experience, one can risk an unlucky fate which is to be expected without the nailing. For the colleagues with the above mentioned troops this method opens new concepts which are interesting but carry great responsibility.

From the Surgical Clinic of the University of Kiel
(Director: Prof. Dr. A.W. FISCHER)

THE RESTAURATION OF CONFIGURATION AND MECHANICAL RELATIONSHIP WITH THE MARROW NAILING METHOD OF KUNTSCHER.

by

Dozent Dr. RICHARD MAATZ
assistant of the clinic

With 12 illustrations

Reprint from
ZENTRALBLATT FUER CHIRURGIE, 70 year/ Vol. 35
1943
Edition: Johann Ambrosius BARTH in Leipzig
printed in Germany

Translation prepared by:
Office of Military Government for Germany (U. S.)
Office of Naval Advisor
Medical Section

Some of the cases of marrow nailing are technically easy to perform. But the difficulties may also be considerable. That they can be overcome is shown by the fact that we never were forced in some 300 nailings to discontinue the operation, as SCHNEIDER (Zbl. Chir. 1942, 1854) reported recently in one of his cases. It is, however, necessary that all technical equipment should be available in the operation room, and that the operating surgeon should have sufficient, at least theoretical, knowledge of the method. It is better to gather some experience in collaboration with someone already skilled. All visitors are very welcome at our clinic. It should not happen, that a nailing is undertaken with insufficient knowledge and incomplete apparatus. It must be avoided that the new fracture treatment should cause more harm than good due to preventable mistakes, and thus be discouraged by the surgical profession on the basis that risk and gain are not in a fair correlation. This danger increases if only a limited number of specially selected successful cases are published. We have reported without restriction about unsuccessful operations at our clinic in Kiel. The number of such cases is unimportant, considering only that our material also includes the first nailings ever performed, and thus those cases in which the early experience was collected. To supplement the reports of KUENTSCHER we published nine months ago a complete report on our further experiences (A.W. FISCHER and MAATZ, Arch. Klin. Chir. 1942) to which we especially refer concerning the matter. In the meantime our experience has further increased, and the sum of them was published in "The technique of the marrow-nailing method" of KUENTSCHER and MAATZ. Permission to print this publication, completed in December, 1942, was delayed during the war.

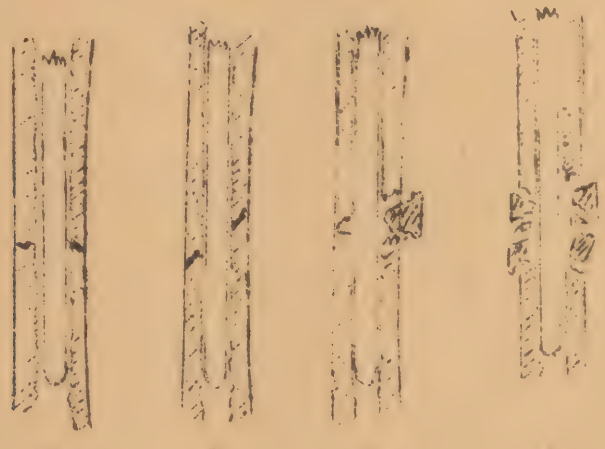
Therefore we considered it necessary to report here about the "restoration of configuration and kinematics by the marrow-nailing method" and to complete the last report of KUENTSCHER on the "technique of marrow-nailing". A.W. FISCHER points out in his preface to that book, that the indications are especially important, and divides fractures into those "very suitable", "suitable", "less suitable" and "unsuitable" for nailing. It is not possible to give a complete list of all imaginable cases of fractures which can be nailed. But we are able to give brief general directions. The surgeon who undertakes to nail should know these directions in detail. He will be able to determine by the X-ray picture, whether a fracture "must" be nailed as there is no better way of treatment, or, whether it is "possible" to nail it or whether the fracture is "not suitable" for this procedure. Moreover, he will also know what he must especially watch for during the post-operative treatment. When can one expect a stabile osteo-synthesis, which must be maintained during the entire process of healing of the fracture? Which eventualities may change a satisfactory stabile osteo-synthesis into an inadequate one early or later? The nailing should, if possible, be regarded as a technical piece of work. Just as the carpenter's nail joins two boards with elastic power, the marrow-nail should connect the bone ends. The nail, driven in by a hammer, should be firmly fixed in both pieces of the broken bone in such a way that every shifting of the bone ends is rendered impossible.

The nail is held by friction of the inner rough walls of the bone cylinder. As the inner diameter of the bone varies, the nail has to possess considerable diameter-elasticity. Therefore, its cross-section is U-shaped. The elasticity would be even greater if the nail had a "bonnet-shaped" cross section[2]. The

two sharp edges of this shape would also be an advantage, as will be explained later on. But technical difficulties have arisen for the present in the construction of sets of these nails.

After a successful nailing the friction between nail and bone can be strong enough to resist several hundred kilograms of force. But the conditions are not equally favorable with all hollow cylindrical bones. The shape of the bone, shape and location of the fracture, and finally the possibility of inserting the nail into the bone cylinder, are all of importance. An ideal nailing cannot be obtained in every case, but even then the new method may provide some advantages.

The most favorable conditions are found in a bone with only minor variations of the diameter of the marrow-cavity, and which can be treated with a straight nail. Location and shape of the fracture are not important in that case, if only both fragments have a sufficient length to provide a satisfactory hold for the nail. It has only to be considered that in case of a defect on one side (breaking out of a piece of bone) the nail is not supported by the bone, but all bending stresses occurring at the location of fracture have to be withstood by the nail itself.



Ill. 1. Ideal conditions for the nailing.
a) direct fracture,
b) transverse fracture,
c), d) defects of the bone cylinder.
Uniform diameter of the marrow-cavity, straight nail.
In cases a) and b) the nail is supported by bone cylinder,
in case c) the nail is not supported by bone cylinder,
thus the nail must withstand strong bending pressures.

If the friction between nail and bone is not sufficient the nail acts as a bolt. It prevents bending of the axis and lateral displacement, but permits rotation. Moreover, the shape of the fracture is of importance for obtaining stability.

The smooth transverse fracture may rotate in either direction, the spiral fracture rotates and shortens, as the oblique planes of fragments slide along each other, and the defect fracture draws closer together until the bones find a hold on one another.

Favorable conditions also occur in the jagged transverse fracture and in short and long oblique fractures. In the first case the muscles press the jagged ends of the fracture together. Thus the fracture is prevented from bending and twisint by the interlocking of the "HIRTH-teeth".

In the case of an oblique fracture a more or less insignificant shortening will occur, which is, however, never of practical importance. It depends on the failure of correlation between the diameter of the nail and marrow-cavity and will continue until the nail and bone are in close contact at the indicated (x) points (Ill. 2b). Beyond that point no further rotation can occur, as it would be combined with a lengthening of the bone cylinder which is strongly counteracted by the muscles.

Less favorable conditions are found in bones having considerable variations in the diameter of the marrow-cavity. If the fracture is located at the part of the marrow-cavity with the smallest diameter, a correct nailing effect can be obtained owing to the diameter elasticity of the nail. Over a range of several centimeters the nail will have sufficient friction in the marrow cavity of both fragments. If this friction is not considerable, the nail acts as a bolt, and thus only prevents lateral displacement. If it is a transverse fracture, the ends of the fracture, which are interlocked and safe against shifting, are also pressed together by the muscles, so that no bending of the axis can occur. Shifting in the sense of rotation is prevented by the interlocking of the teeth.

a b

Ill. 3 Ill. 4

Ill. 2. Favorable conditions at marrow-bolting.
a) toothed transverse fracture
b) oblique fracture.

Ill. 3. Favorable fracture of bone with varying diameter of the marrow-cavity.

Ill. 4. Breaking out of a piece of bone results in a bending of the fracture, until the lower end finds a firm hold at the corticalis.

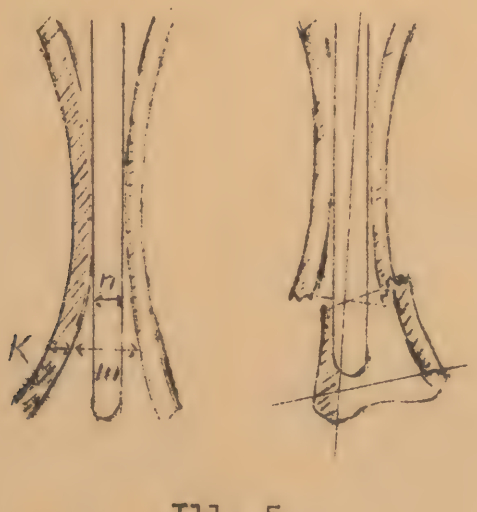
If there is a piece of bone missing at the fracture site, angulation is inevitable.

If the fracture is not located at the narrowest place of the marrow cavity, the shifting which can be prevented by the nail depends on the difference between the width of the bone cylinder and the diameter of the nail. If there is any chance that the ends of the fracture may shift laterally for as much as the thickness of the wall of the bone, we have the least favorable conditions. Dislocation of all four kinds may also occur.

If m - n < K the same principles obtain as those described as "bolting" (Ill. 5).

The situation becomes complicated if the nail is inserted from the side. No rotation between nail and bone cylinder is possible in the fragment through which the nail is inserted, but the strong friction which has to be obtained to join the fragments will in most cases not be achieved, because the nail has to have a smaller diameter than the marrow cavity (Ill. 6a).

If the fracture is located at the narrowest place of a tapering marrow-cavity the differences of diameters will not be very disadvantageous (Ill. 6b). Regrettable and very important is the fact that the nail inserted from the side has to have a considerable elasticity to allow its insertion. When the bone cylinder is again intact after the nailing the bone ends stand one on the other "bend-proof". No dislocations can occur. But if the cylinder of the bone has any defects the bending forces in the nail may easily increase so much that the elastic nail yields and angulation of the axis is the result. This process of deformation of nail and location of the fracture may lead to a visible shifting of the axis. It may, however, appear only when the limb is under weight-bearing and may disappear again when the weight-bearing relaxes. In that case the change of position causes a delay of callus formation owing to the inadequate fixation.



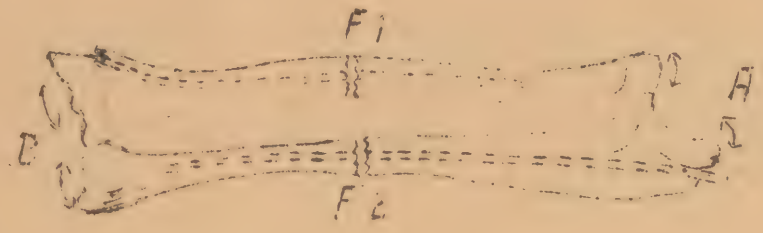
Ill. 5

a Ill. 6 b

Ill. 5. Unfavorable conditions for nailing (or bolting). M - n < K therefore dislocations of all four kinds.

Ill. 6. Insertion of the nail laterally.
a) Unfavorable in care of uniform bone diameter with a nail which must needs be too thin.
b) More favorable with wider diameter of the bone at the place where nail is inserted.

Very favorable conditions are found in twin bones, as in the arm below the elbow. Even if the friction between nail and inner wall of the bone is unimportant, the fragments will never twist at the fracture points F_1 and F_2 (Ill. 7), as the joints always counteract each other. Also a bending of the axis will occur less easily, as both bones support each other securely in at least one plane.



Ill. 7. Favorable conditions in the lower part of the arm.

While the nail rests in the bone, some changes occur which are important and have to be considered. At the inner wall of the cortex the pressure of the nail causes a loss of substance. The friction between bone and nail is decreased by this. As the loss of bone substance is most considerable at the places with the strongest pressure, slide-grooves are formed in the marrow-cavity (KUENTSCHER) (Ill. 8). The more marked these slide-grooves are, the greater is the security against rotation. Therefore nails with sharp edges are to be preferred.

If the nail is round it is to be expected that, even at a late stage of the healing process, a rotation may occur when the nail becomes loose.

Up to this point of the report we have spoken only about the relation of the nail to the bone cylinder (the compacta). Now we also must speak of its relation to the spongiosa of the bone-ends. Though in most cases the hold of the nail in these bone-parts is not important, and one must relaize it is of particular importance in some cases, with regard to the amount of weight-bearing this soft bone tissue can stand.

As an example a case of transplanation of the radius on the ulna near the elbow shall be mentioned. A healing of the bone had not been achieved after five months, owing to infection and the blocking effect of the nail. The joint was practically stiff. The possible movements from 100° to 80° were not permitted by the flexibility of the nail, but were due to the fact that the nail has worked a slot in the spongiosa of the bone, in which the end of the nail had moved 12 mms (see the pictures taken at the same position (Ill. 9). Bone tissue, which is rythmically or constantly put under excessive pressure, reacts with absorption at the place of pressure. Pressure of the nail on the inside of the cylinder of the bones and absorption of the bone tissue at the inner wall of the periosteum causes an active reconstruction of the bone and thus prevents a breaking out of the nail. No similar reaction is to be observed in the spongy part of the bones. The nail creates for itself a bed and finally cuts through the bone.

Ill. 8

Ill. 9

Ill. 8. Slide grooves of the bone.

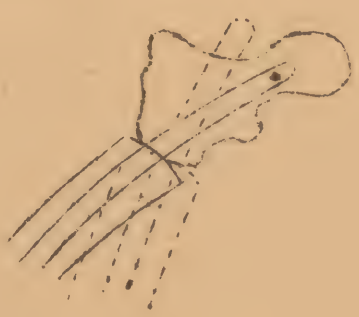
Ill. 9. Movements of the nail in the spongiosa of the ulna.

For instance a subtrochanteric fracture should not be exposed to weight-bearing in its early stages. In cases of a fracture of the ulna near the elbow the end of the nail has to be made particularly broad to prevent the nail from cutting through the bone (Ill. 11).

This fact has also to be considered in the nailing of the radius. The nail, inserted at the proc.styloideus, has to be bent according to the X-ray picture before insertion. If it is left straight the end of the nail will work with elastic forces into the bone and thus into the wrist joint, if the fracture is not in the distal third and the bone can give way with corresponding dislocation at the place of fracture, as reported by EHALT.

The result of a PAUWEL operation as modified by HUENTSCHER strikingly demonstrates the limited capability of spongy bone to withstand weight-bearing. A subtrochanteric osteotomy was performed for coxa vara with a reconstruction zone and the site of the osteotomy was fixed with a marrow-nail. The upper part of the nail was located in the neck of the femur, the lower part in the marrow-cavity. As the tracings of the X-ray pictures (Ill.12), put one on top of the other, show the end of the nail-head worked a considerable hole in the spongiosa of the bone and thus largely frustrated the success of the operation.

Ill.10



Ill. 11 Ill. 12

Ill.10. The nail breaks out laterally at the trochanter major in a case of subtrochanteric fracture bearing weight too early (unfavorable mechanical conditions, due to a stiff knee joint).

Ill.11. The end of the nail-head, which ought to have been bent, destroys the spongious bone with elastic forces.

Ill.12. The nail cuts through the spongious part of the bone after subtrochanteric osteotomy.

The preceding considerations, proven in more than 300 KUENTSCHER-nailings, lead necessarily to the conclusion that only certain fractures of bone shafts can be successfully nailed with the nails available at the present time. The elasticity of the diameter of the nail is too small in most of the cases, thus rendering it impossible always to achieve an effective stabile osteo-synthesis. The shape of the nail must be adapted to the shape of the marrow-cavity as much as possible. The experiments on this subject will be reported on later.

From the Surgical Clinic of the University of Kiel
(Director: Prof. Dr. A. W. FISCHER)

NEW NAIL FORMS FOR MARROW NAILING

by
Dozent Dr. Richard MAATZ
assistant at the clinic

With 11 Illustrations

Reprint from the Zentralblatt fuer Chirurgie, 1943, Nr. 46

Translation prepared by:

U. S. Naval Technical Unit, Europe, (Medical Section)
Office of Naval Advisor
Office of Military Government (US)

In a recent report in this periodical I pointed to the fact that some of the fractures of long bones treated with a simple KUENTSCHER-nail may not be stabile, and the fragments of the fractured bone would still be free to change their position. For this reason it is not possible to properly call those cases "stabile osteo-sythesis". But if this cannot be obtained it is not to be expected that callus will form quickly and undisturbed. Even the parts of the fracture may shift so badly that the resulting position must be recalled "faulty". (Fehlstellung). For these reasons EHRLICH now has begun to place every fracture of the tibia in a plaster cast for a few weeks following the nailing as a preventive measure. We reported about a year ago (A. W. FISCHER and MAATZ) that nearly 50% of all fractures of the tibia had to be provided with an additional plaster cast. But this has the disadvantage that the limb cannot be moved, and compound fractures may be treated from all sides only with difficulty to prevent infection, which are supposedly the main advantage of the nail method. New ways had to be found to eliminate the necessity of the plaster bandage.

Inadequate stabilization of some fractures may depend on the shape of the marrow-cavity, the location of the fracture and its form, as well as on the shape of the nail or the place where it is inserted. I refer the reader to the previously mentioned report and will now publish the experience with new forms of nails.

In case of <u>the humerus</u> it must be remembered that the marrow cavity is conic in a sense, that it is wide proximally and narrow distally. Thus it is recommended to insert the nail proximally. That means in most cases, as suggested by HAEBLER, inserting the nail through the deltoid muscle below the head. The width of the marrow cavity determines whether it may be sufficient to use a normal double - nail or whether it is more advisable to drive a conic wedge between the two nails. To this end it will be necessary to enlarge the hole in the side of the bone vertically so that there may be sufficient space for nails and wedge.

Illustration 1

The wedge between the nails

In <u>the forearm</u> only the fracture of the ulna near the elbow requires an especially shaped nail. In that case the marrow cavity is very wide , the proximal part of the nail can only be fixed in the spongy bone and in addition to this the bending forces acting on the nail

are very great . These facts determine its shape. It has to be broad proximally to prevent cutting through the spongiosa, must have a considerable diameter at the place of the fracture to be bend-proof, and must be conical in the distal direction to find sufficient room in the narrow marrow cavity. It would be a mistake to choose a short nail, as it must receive sufficient friction in the marrow-cavity over a wide area since otherwise it would work out of the bone automatically. To prevent such a "wandering" of the nail its head-end has to be made a little thinner. To make the insertion as well as the eventual removal of the nail easier, the differences of the diameters are marked in distinct steps. Thus the nail "eats" its bed into the spongiosa at its insertion and cannot stick in the bone when removed later. The use of this technique also avoids the use of a large drill-hole in which the nail would find inadequate support.

Illustration "
Special nail for a fracture of
of the ulna near the elbow

With the femur, the conditions which are related to the treatment of the fracture with the simple marrow-nail are much more favorable. The marrow cavity has the same diameter for nearly its whole length in any case in the part where most fractures are observed. In addition to this, a straight nail can be inserted thus ensuring a stable osteosynthesis in most of the cases. Consequently all authors, who have reported about any experience with the marrow-nailing method, state that the new method of treatment is a considerable advance, especially in the femur (EHRLICH, SPRENGEL, BOEHLER, HAEBLER, HERZOG, BAUER, CELLARIUS, HEIM etc). But even in some of these cases the question may arise about the shape of the nail which might fit better into the shape of the marrow cavity than does the ordinary nail.

The marrow cavity of the femur is distinctly conic below the trochanter. Fractures in this region, especially oblique fractures, may show a lateral displacement and a corresponding shortening though the marrow nail was used. This disadvantage may be easily prevented by the insertion of a nail sufficiently thick and conic in form. The thickness of the sheet from which the nail is made may be kept very small to prevent the nail from being too heavy. At the same time the nail gets a broader support in the trochanter major, allowing the patient to bear weight earlier without running the risk that the nail may cut through the spongiosa.

Illustration 3
Subtrochanteric transverse fracture a) with normal, b) with conic marrow nail.

The use of such a nail is especially important in the spontaneous fracture associated with tumor-metastasis. Experience has shown that the marrow cavity is unusually wide in bones so affected and in such way that an ordinary nail will never be sufficient, In fractures of this sort the stabilization by a marrow nail for a rather long time is urgently needed, as it can never be known, when a healing of the bone may take place or if it will do so at all. In two cases nailed by us, the smallest diameter of the nail was 16 millimeters.

The younger the patient the more distinct is the marrow portion of the marrow cavity at the middle of the femur. The more distal the fracture is located from this place, the more will be the required nail which will fit into the shape of the marrow cavity. Our experiments in this respect are not completed as yet. The illustration gives an example of a possible solution. Two nails are used with an U-shaped cross section, which are put into one another in such a way that one side of the U is lodged between the sides of the other U; and owing to the shape of the nails, which are driven in so that one nail goes in a little ahead of the other, the points of the two nails spread, thus increasing the total cross-section of the nail. But the insertion of these nails may cause difficulties. For this reason we have not as yet started a large production of this design.

Illustration 4

Double-nail for the femur

Experiments with other models promise better success. As soon as sufficient experience has been gained a detailed report will be given.

The stabile osteosynthesis is particularly difficult to obtain in the lower leg as the marrow cavity has a distinct narrow part in the middle, the nail has to be inserted laterally and this nail has to be springy.

Illustration 5

Fractures above the narrowest part of the marrow-cavity can be provided fairly easily with conic nails, if necessary by inserting a third, shorter nail or in special cases a conic wedge between the nails.

Though fractures of the tibia in the middle of the shaft are not so serious, as the nail can always be lodged close to the inside of the bone, the simple double-nail does not guarantee an absolutely correct position of the axes of the fragments.

Illustration 6
Insertion of the turn-spread-nail into the tibia.
a) Insertion of the inner nail before turning
b) Insertion of the outer nail after completed insertion of the inner one.

It is liably to recurve and this may even be furthered by the curvature of the nail. A turn-spread-nail has given excellent results in these cases as well as with transverse fractures, which are located distally to the narrowest place of the marrow cavity. The outer nail matches the one so far used in the simple double nail. The inner nail is S-shaped, massive, elastic, with an oval cross-section. The inner nail is first driven in completely. Its position during the insertion is shown in the illustration (Ill. 6). It is turned by 180° when approximately two thirds of its

length have been inserted in the bone. The point of the nail then has enough room in which to turn. The head of the nail is furnished with a slot in which a screw-driver can be inserted to turn the nail. If any difficulties arise owing to a sticking of the point of the nail on the rough inner surface of the bone, it is easier to turn the nail while driving it in further.

Illustration 7

Short transverse fracture of the tibia with turn-spread-nail.

After the inner nail has been driven completely in, it is prevented from going in any further, during the insertion of the outer nail, by means of a wire or a cross-pin which are inserted in the hole at the head of the nail.

The outer and inner nail together form quite a massive cross-section in the region of the narrowest part of the marrow cavity, though the cross sections are of such a shape that the surfaces of the nails do not touch one another over a wide space. The total cross section must be smaller than the diameter of the marrow cavity to prevent the nails from completely filling the marrow space (fat embolism). This has the disadvantage that this nail does stick fast neither at the narrowest part of the marrow cavity nor at any other place of the bone. Therefore it is really only a matter of "bolting". For this reason this nail cannot be used with fractures in the distal part of the marrow cavity of a triangular form, nor for oblique fractures, in which cases an absolutely tight wedging of the nail and the inner surface of the bone has to be obtained.

With these fractures it is better to use <u>the spread-nail with an inclined plane</u>. The points of the nails are spread apart by an inclined plane, which is attached to the outer nail so as to direct the inner nail backwards. Of course the outer nail which has an inclined plane must be driven in first, and the inner nail must cross the inclined plane only after the inclined plane has penetrated the bone distally far enough so that there will be sufficient space between this plane and the opposite rear wall of the tube of the bone. This cannot be achieved until the outer nail is completely driven in. Then, during the driving in of the inner nail, a further penetrating of the outer nail into the marrow cavity is prevented by fixing it with wire and counter-traction. It is recommended, to drive both

nails in at the same time in such a way, that the outer nail advances ahead of the inn r nail far enough to place the point of the inner nail close behind the inclined plane.

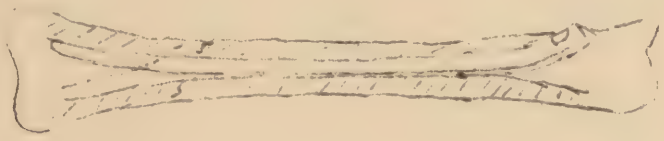


Illustration 8

To achieve this, a special device is needed to keep the points of both nails in a correct relation while being inserted. (Schlag Aufsatz) (Ill. 9).. If this is not available the outer nail must be driv n in completely first. But then there may arise the disadvantage that because of the inevitable great friction the insertion may be rendered very difficult. In using this nail it is essential that the inclined plane should be located at a correct hight. For this there must be chosen the place where the two nails in the distally exparding marrow cavity have space enough side by side. This is the point, where the end of the plane has to be located. Generally the distance of this place from the point of the nail is 5-7 centimeters. In any case it should be measured from the tip. Minor miscalculations of the total length of the nail may be corrected by driving the nail in more or less deeply. It is a matter of course that the determination of the length of the nail should be made very carefully.

Illustration 9

Nails in the lower leg are sometimes liable to rotate inside the marrow cavity. This may be due to the fact that the nail is unintentionally driven in a little medially or laterally from the central axis of the marrow cavity into the tuberosities. Thus the nail must ... make a rotation by which it approaches the middle of the marrow cavity. Another reason may be the more or less distinct oval shape of the shin-bone. The nail has to fit into that curvature and it is easier for the nail to make a rotation of 45-90° than to bend sideways.

We became aware of these facts only when using the spread nails and are now endeavouring to eliminate these shortcomings. We are trying to place the level of spreading at the point most favorable to the fixation of the fracture. If the points of the nails are intended to lie close to the tube-bone at the front and back, the place

for introducing the nail at the tuberositas has to be at the center of the marrow cavity (to be determined by means of X-rays). Furthermore an attempt must be made to prevent any ultimate rotation of the nail (Ill. 10a). But in case of an oblique fracture, as shown in Ill. 11, the place of inserting the nail has to be placed more medially. The outer nail will turn inwards unassisted.

Illustration 10

Fractures of the tibia with Spread-nail with inclined plane.

The triangular support of the spread-nail with inclined plane is a very stabile system. Generally a stabile osteosynthesis can be obtained in that way. But all our attempts to have patients with fractures of the lower leg ambulatory then the third postoperative week did not have good results. Even when there occurred no shifting of the fragments or pains at the cleft of the fracture, the most certain signs of inadequate fixation, as well as swellings appeared. Therefore we recommend that fractures of the lower leg should not be made ambulatory before the end of the third week.

Anyhow, the principal advantage of the stabile osteosynthesis is the possibility to exercise the leg freely in bed by unhampered motion.

The above mentioned sample of the nail for the ulna showed already that it is necessary in special cases to use serrated nails. They are always to be used if there is some danger that the nail may stick fast in a markedly conic marrow cavity. This is particularly apt to happen in the marrow callus of a fracture originally healed in a faulty position which has been treated by osteotomy and then nailed. In that way a surgical intervention is made easier, as it is not necessary to widen the marrow tube. Thus the advantage is gained that the nail lies absolutely stabile in the tube of the bone. The device of the serrated nail is absolutely necessary if a fracture with delayed formation of callus is to be nailed per-

cutaneously. Also, the serrated nail may be helpful in the removal of the nail. This will be necessary for instance, when Y-nails are used. These nails widen into spoonshape in the distal part of the marrow nail, to provide the nail with sufficient friction in the marrow cavity in order to prevent rotation. The proximal part of the nail has a smaller diameter and the removal of the nail can only be accomplished without difficulties when serrations directed backwards cut the callus. As an example of such a case an osteotomy of the femur may be mentioned. The bone was exposed in the way proposed by KUFNTSCHER. After the covering layer of the bone has been removed, the marrow cavity was not widened. To secure a good fit of nail and bone the proximal part of the nail was built conical and this conical part was provided with serrations (see Ill. 11).

Illustration 11

Osteotomy of a fracture of the femur healed faulty.

Beyond this we do not consider it necessary to give illustrations of other possibilities.

The nails were developed in collaboration with the firm of POHL. The spread nail has been used 7 times, the turn-spread-nail 5 times until the present (Ed.Note 1943). The experiments led to very good results. Thus, at our clinics the simple double nail is not used any more in the leg below the knee. It is expected that at other places the development will be on the same lines, for even in the most favorable case, the transverse fracture at the narrowest place of the marrow cavity, the turn-spread-nail is to be preferred as it prevents the otherwise easily occurring recurvature. Difficulties encountered the first time this method is used, will be mastered soon. Both kinds of nails are manufactured in the used lengths up to now. The end of the inclined plane (the middle of the block which bears the inclined plane) is at a distance of 5-8 centimeters from the point of the nail. Thus every hospital will have the possibility to shorten the nail for a short bit on the whetstone. After that the nail has to be pro-

vided with the correct curvature, which inclines toward the other nail to facilitate its insertion into the distal fragment of the bone. Another possibility is to supply sets of nails with a separate inclined plane which can be attached to the nail at the place desired at the operating hospital. It has,however, to be considered that the riveting has to be done very carefully, as the block must not get loose under any circumstances. The necessary drills and drill pattern and the rivets already fixed on the block have to be delivered by POHL separately. This has, however, to be regarded as a temporary solution for the time being. During the war it was not possible to supply every hospital with a complete set of marrow-nails made on HERZOG's improved lever-device for use in marrow nailing. I recommend as a temporary expedient that the single nails should be ordered by telegraph. It has been arranged with POHL to order the turn-spread-nail for the leg briefly as "turn-nail 32" the number indicating the length in centimeters and to abbreviate the spread nail: "spread nail 32/5" , the first number indicating the length, the second number the distance from the end of the inclined plane to the point of the nail in centimeters. It is only in cases of compound fractures of the leg that the nailing must not be delayed for 2 or 3 days.